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GRAPEVINE LOOPER.

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INTRODUCTION.

The grapevine looper (*Lygris diversilineata* Hübner.)¹ is an insect enemy of the grapevine and Virginia creeper, causing injury by defoliating them. It is one of a group of leaf-feeding caterpillars known as geometrids, or measuring worms, of which the cankerworms are among the best known. It has been known as a grapevine pest for more than 70 years and occasional accounts of damage due to it have been published, but hitherto accounts of its biology and seasonal history, in particular, have been incomplete. The present paper is a record of studies of its biology and control, conducted at North East, Pa., in the Erie-Chautauqua grape belt during the seasons of 1916 and 1917.²

DISTRIBUTION.

The grapevine looper is found in northeastern United States and southern Canada. In the literature of the species its occurrence is noted from the following States: Massachusetts, New York, Illinois (4);³ Maine, New Jersey, Pennsylvania, Michigan (8); Wisconsin (10); and Missouri (18). It has also been recorded from

¹ Order Lepidoptera, family Geometridae.

² The writer wishes to thank Mr. E. R. Selkregg for preparing abstracts of most of the literature cited herein, Mr. J. K. Primm for assistance in life-history studies in 1916, and Mr. J. H. Paine for preparing all illustrations except Plates III, A, and IV, B.

³ Reference is made by number (italic) in parenthesis to "Literature Cited," p. 14.

Orilla, West Canada (4), and the provinces of Ontario and Nova Scotia (15). The writer has collected it in the States of New York, Pennsylvania, and Ohio.

FOOD PLANTS.

The grapevine was first recorded as a food plant of this species by Gueneé (3), and the Virginia creeper or woodbine by Saunders (5). *Vaccinium* was given by Gueneé as the food plant of his synonym *gracilineata* (3). Packard (16) published a note by Riley which lists as food plants the laurel, oak, elm, pear, apple, cherry, and the rose. This note states further that the larvæ entered the ground June 5, and adults emerged November 9. Since this differs so strikingly from the habits and duration of the pupal period of the species in question, it is obvious that Riley's observations relate to another species. The writer has observed it feeding on grapevines (*Vitis* spp.) and the Virginia creeper (*Parthenocissus quinquefolia*).

SYSTEMATIC HISTORY.

The grapevine looper was figured by Hübner in 1806 (1) as *Petrophora flava diversilineata* and later (2) was transferred by him to the genus *Euphia*. Gueneé (3) placed it in the genus *Cidaria*. This name is used interchangeably with *Petrophora* in practically all of the literature following until Dyar (22) listed it as *Eustroma diversilineata* Hübn., although Comstock (19) and Hulst (20) had previously used this nomenclature. Gumpfenberg (17) placed both *Petrophora* and *Cidaria* in synonymy with *Lygris*, and listed the species as *L. diversilineata* Hübn. This nomenclature has been followed in the most recent check-list of North American Lepidoptera (26). The generic name has been spelled *Petrofora* (10), but this is undoubtedly a typographical error.

There is only one synonym of this species, *L. gracilineata* Gueneé (3). This was reduced to synonymy by Packard (8), but was later given rank as a variety by Grote (11).

SYNONYMY.

- 1806. *Petrophora flava diversilineata* Hübner (1).
- 1816. *Euphia diversilineata* Hübner (2).
- 1857. *Cidaria diversilineata* (Hübner) Gueneé (3).
- 1857. *Cidaria gracilineata* Gueneé (3).
- 1890. *Lygris diversilineata* (Hübner) Gumpfenberg (17).
- 1895. *Eustroma diversilineata* (Hübner) Comstock (19).

COMMON NAME.

This insect was first called the "grapevine *Cidaria*" by Saunders (12) and because of the wide distribution of his general work on fruit insects this name is quite well known. After *Cidaria* became obsolete as the generic name, Lugger (21) called it "the grapevine *Petrophora*." This generic name has also been superseded. A name

descriptive of the larva, "the grapevine looper," was first applied by Fletcher (15) in 1887, and "the grapevine geometer" was the name used by Bethune (24) in 1907. Comstock (19) and Holland (23) used the name "diverseline moth." It would seem to the writer that the most serviceable name for an economic insect would be one descriptive of the destructive stage. For this reason he has followed Fletcher in using the name "grapevine looper." This is also the oldest name in use except that proposed by Saunders, which has become obsolete because of the change in the generic name.

ECONOMIC HISTORY.

The grapevine looper was first recorded as a pest of economic importance by Saunders (6) in 1870, and in following years was referred to by him and his colleagues as destructive in Ontario (7, 12, 15, 24). Damage done by this insect not only to hardy grapes but particularly to grapes under glass is recorded by Hoy (10). It is referred to as an economic insect in Illinois (9, 13), and is mentioned by Hartzell (25) in his report on grape insects in New York.

DESCRIPTION OF STAGES.

THE EGG.

The egg (Pl. I, A, B) is elongate ovate, with one end rounded and considerably wider than the other. The small end, which forms the micropyle, is flattened and has a scalloped rim encircling it. The shell surface is reticulate with irregular hexagonal areas, which are particularly conspicuous on the "rim" of the micropyle. The color is pale greenish yellow when first deposited, becoming lavender in about two days. Length 0.75 mm., greatest diameter 0.42 mm., diameter of micropyle 0.30 mm.

In a week or 10 days after the eggs are deposited they become somewhat depressed on the upper side. The shell is very durable and, even after the hatching of the egg, remains without breaking or shrinking for several weeks.

THE LARVA.

The larva (Pl. II) is very elongate and slender, the total length being about eighteen times greater than the greatest breadth. In general it is cylindrical, as tapering toward either end is slight. The head is flattened in front and strikingly bilobed dorsally, each lobe being bluntly pointed. The thorax and abdominal segments 7 to 10 are very short, while abdominal segments 1 to 6 are very long, making up three-fourths of the entire body length. The dorsal plate of the tenth segment is paraboloid, and two elongate processes from the ventral part of the segment protrude under it. Only the last two pairs of prolegs are present; the first of these, although belonging to the seventh segment, appears to arise between this segment and the sixth. This pair of prolegs is large and fleshy, while the pair arising from the tenth segment is wide, flat, and straplike.

The color is usually a pale green with pink or reddish markings. The extent of these markings varies and, while most frequently they are confined to the legs and a median ventral stripe, occasional larvæ are nearly all of some shade of red. Superficially the larva appears to be naked, but there are fine setæ on every segment.

Mature larvæ have a total length averaging 37 mm. and a head width averaging 2.05 mm.

Larvæ of all instars are practically alike in structure, except that the head is less distinctly bilobed in the earlier instars and not at all in the first instar.

THE PUPA.

The pupa (Pl. IV, A, B) is slender; its greatest width is at the thorax and it gradually tapers anally. The wing covers extend to the middle of the fourth segment. At the tip of the anal segment is a cremaster which bears four pairs of strong coiled hooks. The color is light green throughout, except the cremaster, which is flesh colored. Superficially the pupa appears to be naked, but under a high-power lens setæ are found on all segments except the last.

THE ADULT.

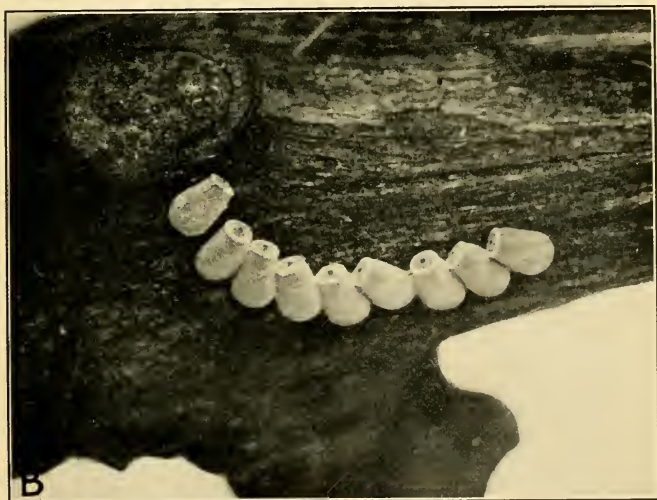
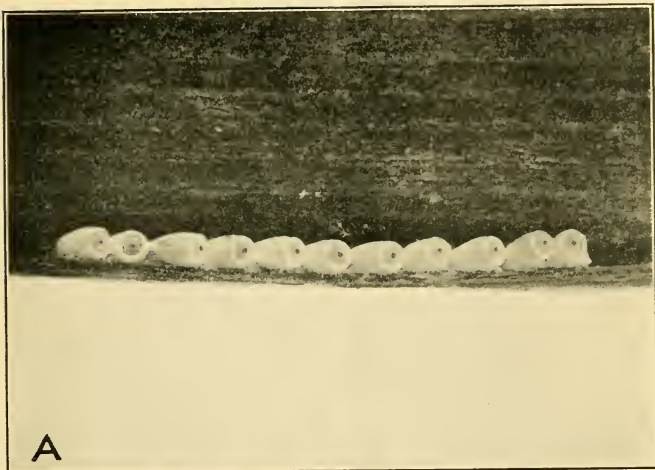
When Hübner (1) named this species he figured the adult (Pl. IV, C) in water colors, but gave no description. The following description of the adult is copied from Packard (8):

30 ♂ and 10 ♀.—Palpi long. Fore wings falcate; outer edge almost angular. Hind wings slightly scalloped. Body and wings of a uniform ochreous-yellow; palpi dark in front of the head, tipped with dark-brown. Fore wings uniformly ochreous; a curved, basal, rust-brown line, denticulated on the veins; beyond, two parallel, more distinct, concolorous lines, the inner a little wavy, directed obliquely to the inner edge; the outer makes a right angle in the submedian space, crosses the inner line, forming a broad, triangular enclosure on the inner edge of the wing; beyond is a broad space, just beyond the middle of the wing, usually filled in with a purplish-brown tint, disappearing before reaching the costal space; sometimes there are two central lines in this space, converging a little below the median vein and forming large ringlets; this mesial space is bounded externally by a dark, rust-brown line, which ends at the same distance from the base of the wing both on the costa and inner edge; in the first median space it forms a large, sharp projection; beyond is another concolorous line, which curves inward to where it is usually (not always) interrupted by the projection of the other line, and thence goes straight, though zigzag in its course, to the inner edge of the wing; a similarly colored more or less zigzag, oblique, apical line extends to the middle of the wing, opposite the projection; the edge beyond the lines either clear-yellow or filled in with lilac-brown; a small discal dot. Hind wings clear, a little paler than the fore wings, with a faint discal dot, sometimes absent; in the outer third of the wing an angulated, faint, violet-brown line, edged externally with silver, a heavier, diffuse, shorter, submarginal, dark-brown, zigzag line, with a slight violet tinge; the space between this and the wing suffused with violet-brown, extending only toward the middle of the wing, or sometimes passing beyond toward the apex. Beneath, the wings are yellow ochreous, speckled, especially on the hind pair, with coarse, violet-brown specks. Fore wings clear when covering the hind ones, with three costal spots, the third in the middle of the costa; beyond, the angulated outer line is reproduced; apical, oblique line distinct, with a violet-brown cloud below. Hind wings with three regularly-scalloped lines; the margin of the wing broadly clouded with violet-brown. Legs yellow; joints tipped with violet-brown. Abdomen yellow, tinged above with rust-brown.

Length of body, ♂ 0.60, ♀ 0.50-0.60 * * *; expanse of wings, ♂ 1.30-2.10, ♀ 1.35 inches.

LIFE HISTORY AND SEASONAL HISTORY.

The immature stages of this insect have been known since 1876 (8), but data regarding other biological phases have been meager and some misconceptions have arisen. Saunders (6) first sketched its seasonal history. He recorded the occurrence of larvæ in the



THE GRAPEVINE LOOPER.

Eggs on grape canes, showing (A) end view and (B) side view.



LARVA OF THE GRAPEVINE LOOPER.



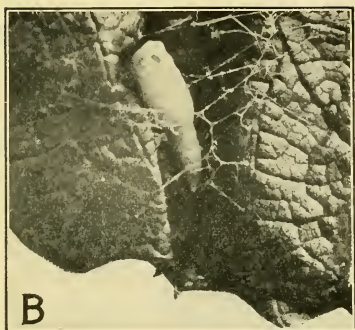
A



B

WORK OF THE GRAPEVINE LOOPER.

A, Grape leaf being devoured by fifth-stage larva; B, grape leaf showing around edges typical feeding marks of early stages of the looper.



THE GRAPEVINE LOOPER.

A, Pupa, enlarged; *B*, pupa, in pupal web on grape leaf, enlarged; *C*, adult or moth, enlarged.

spring and of moths in June and August, and stated that *probably* eggs are deposited in the fall, produce larvæ which attain full growth before winter, and after hibernation "resume their destructive labors with the opening of spring." In the following years a number of authors repeat, without any qualification whatever, that the grapevine looper is two-brooded and hibernates as an immature larva. Forbes (13) recorded the collection of larvæ September 13 in southern Illinois and concluded that it is two-brooded in that latitude. Packard (8) stated that *perhaps* this insect is two-brooded in Texas, but he apparently regarded it as single-brooded farther north.

STUDIES AT NORTH EAST, PA., IN 1916.

Life-history studies of the grapevine looper really began in the summer of 1916, although miscellaneous observations had been made during the two preceding seasons. The attempt was first made to rear several hundred larvæ in battery jars, but with large numbers crowded together the mortality was very high. It was finally found best to isolate them in large shell vials. This method was followed altogether in the handling of larvæ in 1917, although it necessarily limited the number that could be studied. Adults were caged in battery jars.

The studies were begun with collected larvæ for the purpose of learning the duration of the pupal period and the time of emergence of moths and securing eggs for the next generation. These data are given in full in Table I.

TABLE I.—Records of pupation and eclosion of moths of the grapevine looper, North East, Pa., 1916.

Number of individuals.	Date of pupation.	Date of eclosion of adults.	Duration of period.	Number of individuals.	Date of pupation.	Date of eclosion of adults.	Duration of period.
			<i>Days.</i>				<i>Days.</i>
2.....	July 9	July 19	10	3.....	July 24	Aug. 3	10
1.....	9	20	11	1.....	25	3	9
2.....	10	20	10	3.....	25	4	10
1.....	12	22	10	1.....	25	5	11
1.....	16	25	9	1.....	26	4	9
1.....	17	26	9	6.....	26	5	10
1.....	18	27	9	4.....	27	6	10
1.....	18	28	10	3.....	28	7	10
1.....	20	30	10	1.....	28	8	11
3.....	22	31	9	1.....	29	7	9
1.....	22	Aug. 1	10	1.....	29	8	10
3.....	23	1	9	1.....	30	8	9
2.....	23	2	10				
2.....	24	2	9	48 1.....			2 9.75

¹ Total.

² Weighted average.

DURATION OF PUPAL PERIOD.

The pupal period of 48 individuals varied from 9 to 11 days, with an average of 9.75 days, as shown in Table I. The total period extended from July 9, the earliest record of pupation, to August 8, the latest record of eclosion of an adult.

ECLOSION OF MOTHS.

Transformation of pupæ to adults occurred during the period from July 19 to August 8, the majority of them having appeared by August 3. The dates of eclosion are shown in Table I.

HIBERNATION IN THE EGG STAGE.

By miscellaneous rearings in the season of 1915, the writer had learned that moths of this species appeared in midsummer, and according to most of the available information the insect was two-brooded. Consequently the eggs secured in cages were expected to produce a second generation in 1916. There proved to be only one generation, however. When the eggshells appeared to give way and the eggs became depressed (see description of egg), it was feared that they were infertile and a persistent search for second-brood larvæ in vineyards where the first brood had been abundant was begun. Not a single larva was found, nor did a single egg hatch that season, although it was shown by hatching records the following season that practically all of the eggs were fertile.

STUDIES AT NORTH EAST, PA., IN 1917.

The time of hatching of larvæ in 1917 and the time of occurrence and duration of the larval, pupal, and adult stages are given in Table II.

TABLE II.—*Dates of hatching and of occurrence and duration of stages of the grapevine looper, North East, Pa., 1917.*

Number of individuals.	Date of hatching.	Date of spinning cocoon.	Duration of feeding period.	Date of pupation.	Duration of prepupal period.	Date of eclosion.	Duration of pupal period.	Total duration of immature stages.
			<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	<i>Days.</i>
1.....	June 2	July 17	45	July 19	2	July 29	10	58
1.....	2	21	49	23	2	Aug. 2	10	61
1.....	2	21	49					
1.....	2	25	53	July 27	2	Aug. 5	9	64
1.....	3	17	44	19	2	July 29	10	56
2.....	3	19	46	21	2	30	9	57
1.....	3	20	47	22	2	31	9	58
4.....	3	21	48	23	2	Aug. 2	10	60
1.....	3	22	49	24	2	3	10	61
1.....	3	24	51	26	2	5	10	63
1.....	3	25	52	27	2	6	10	64
1.....	4	18	44	21	3	July 30	9	56
1.....	4	19	45	21	2	30	9	56
2.....	4	21	47	23	2	Aug. 2	10	59
1.....	4	22	48	24	2	4	11	61
1.....	4	24	50	26	2	5	10	62
3.....	5	17	42	20	3	July 31	11	56
2.....	5	19	44	21	2	31	10	56
1.....	5	20	45	21	1	30	9	55
2.....	5	20	45	23	3	Aug. 1	9	57
1.....	5	21	46	23	2	2	10	58
1.....	5	23	48	24	1	2	9	58
1.....	5	23	48					
1.....	5	24	49	July 26	2	Aug. 5	10	61
2.....	5	25	50					
1.....	6	17	41	July 19	2	July 29	10	53
2.....	6	19	43	21	2	31	10	55
1.....	6	21	45	23	2	Aug. 1	9	56
1.....	7	20	43	22	2	1	10	55
1.....	7	21	44	23	2	2	10	56
2.....	7	22	45	24	2	4	11	58
1.....	7	23	46	24	1	1	8	55
1.....	7	23	46	24	1	2	9	56
2.....	7	24	47	26	2	Aug. 5	10	59
1.....	8	24	46	26	2	6	11	59
2.....	8	27	49	29	2			

TABLE II.—*Dates of hatching and occurrence and duration of stages of the grapevine looper, North East, Pa., 1917—Continued.*

Number of individuals.	Date of hatching.	Date of spinning cocoon.	Duration of feeding period.	Date of pupation.	Duration of prepupal period.	Date of eclosion.	Duration of pupal period.	Total duration of immature stages.
			<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	<i>Days.</i>
1	June 9	July 20	41	July 21	1	July 31	10	52
1	9	21	42	24	3	Aug. 2	9	54
1	9	22	43	24	2	2	9	54
1	9	23	44	25	2	3	9	55
1	9	26	47	28	2	8	11	60
1	9	28	49	30	2	8	9	60
1	10	25	45	27	2	6	10	57
1	10	26	46	28	2	8	11	59
1	10	27	47	29	2	9	11	60
1	11	23	42	25	2	5	11	55
1	11	24	43	26	2	4	9	54
1	11	28	47	30	2	9	10	59
1	11	30	49	Aug. 1	2	12	11	62
1	11	31	50	1	1	12	11	62
1	13	26	45	July 28	2	7	10	57
1	14	26	44	28	2	8	11	58
1	15	27	44	29	2	8	11	57
1		10		13	3	July 24	9	
1		12		15	3	29	14	
1		13		16	3	27	11	
1		15		17	2	24	12	
1		20		22	2	Aug. 1	10	

TIME OF HATCHING.

The period of hatching of eggs in cages extended from June 2 to June 15, half of the larvæ having hatched by June 5. These dates are shown in Table II. Vineyard collections indicated that a few larvæ hatched fully a week earlier under natural conditions, for one newly molted larva of the second instar was collected June 2, and others collected in vineyards a little later were distinctly more advanced in development than those hatched in the insectary and matured about a week earlier. Vineyard observations showed, however, that the hatching period of the bulk of the brood is quite well covered by the insectary records.

DURATION OF LARVAL FEEDING PERIOD.

The duration of the larval feeding period, of 66 individuals reared, varied from 41 to 53 days with an average of 46.12 days. Records of the feeding period extended from June 2, date of the earliest recorded hatching, to July 31, date of the latest recorded spinning of the cocoon or pupal web. As previously stated, a few larvæ must have occurred in vineyards earlier than these records show. Compared with other leaf feeders on grapevines, this insect has an unusually long period for larval development, and consequently an unusually long period during which it may be destroyed by poison sprays.

TABLE III.—*Duration of the larval feeding period of the grapevine looper, North East, Pa., 1917.*

Number of individuals.	Duration of feeding period.
	<i>Days.</i>
2	41
5	42
5	43
8	44
10	45
7	46
7	47
7	48
8	49
4	50
1	51
1	52
1	53
1 66	2 46.12

1 Total. 2 Weighted average.

DURATION OF FIRST LARVAL STAGE.

The duration of the first larval stage of 72 individuals reared varied from 8 to 12 days with an average of 9.19 days. These data are shown in Table IV. Records of this stage cover the period from June 2, the earliest recorded date of hatching, to June 24, the latest recorded date of passing the first molt.

TABLE IV.—*Duration of first larval stage of grapevine looper, North East, Pa., 1917.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
18	8
34	9
12	10
4	11
4	12
¹ 72	² 9.19

¹ Total. ² Weighted average.

TABLE V.—*Duration of second larval stage of grapevine looper, North East, Pa., 1917.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
14	7
35	8
12	9
5	10
1	11
¹ 67	² 8.16

¹ Total. ² Weighted average.

DURATION OF SECOND LARVAL STAGE.

The duration of the second larval stage, of 67 individuals reared, varied from 7 to 11 days with an average of 8.16 days. With the exception of one second-stage larva collected June 2, records on this stage extended from June 10, when the first larva passed the first molt, to July 2, when the latest larva passed the second molt. Data relating to the duration of this stage are summarized in Table V.

TABLE VI.—*Duration of third larval stage of grapevine looper, North East, Pa., 1917.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
1	6
7	7
16	8
24	9
12	10
3	11
4	12
¹ 67	² 8.95

¹ Total. ² Weighted average.

DURATION OF THIRD LARVAL STAGE.

The duration of the third larval stage, of 67 individuals reared, varied from 6 to 12 days with an average of 8.95 days. These data are summarized in Table VI. The records on this stage extended from June 19, when the earliest larva passed the second molt, to July 11, when the latest passed the third molt.

DURATION OF FOURTH LARVAL STAGE.

The duration of the fourth larval stage, of 65 individuals reared, varied from 6 to 17 days, with an average of 9.71 days. These data are summarized in Table VII. The total period during which larvæ of this instar were recorded extended from June 26, when the earliest larva molted the third time, until July 19, when the latest larva molted the fourth time.

TABLE VII.—*Duration of fourth larval stage of grapevine looper. North East, Pa., 1917.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
4	6
10	7
6	8
13	9
10	10
10	11
2	12
6	13
2	14
1	15
1	17
1 65	2 9.71

¹ Total. ² Weighted average.

TABLE VIII.—*Duration of feeding period of fifth larval stage of grapevine looper North East, Pa., 1917.*

Number of larvæ.	Duration of period.
	<i>Days.</i>
1	7
8	8
23	9
11	10
17	11
3	12
3	13
2	14
1 68	2 9.97

¹ Total. ² Weighted average.

DURATION OF FIFTH LARVAL FEEDING STAGE.

The duration of the fifth larval feeding stage, of 68 individuals reared, varied from 7 days to 14 days, with an average of 9.97 days. The data are shown in Table VIII. This period includes all of the fifth stage except the period after spinning the cocoon, or the prepupal period. Records on the feeding period of larvæ of this instar extended from June 29 to July 31.

DURATION OF PREPUPAL PERIOD.

The duration of the prepupal period, of 68 individuals reared, or the time following the formation of the cocoon until pupation, is usually 2 days, although there are four records of 1 day and 10 of 3 days, as shown by Table II. This variation is not significant since observations were made only once a day, and it would be possible for an individual which required a little less than two days to have been noted only once during that time, or for one which required slightly more than two days to have been noted three times.

DURATION OF PUPAL PERIOD.

The duration of the pupal period, as shown by Table II, was practically the same as the preceding year, 63 of the 66 individuals under observation requiring 9 to 11 days, with an average of 10.18 days. The extremes, however, extended from 8 to 14 days. The records on

this period extended from July 13, the earliest recorded date of pupation, to August 12, the latest recorded date of eclosion of an adult—exactly the same length of time as recorded for 1916.

ECLOSION OF MOTHS IN 1917.

Eclosion of moths in 1917 extended from July 24 to August 12, with the height of the period about August 2. The dates of eclosion of moths reared are given in Table II.

SUMMARY.

There is one generation annually in the Erie-Chautauqua grape belt, winter being passed in the egg stage. Insectary records in 1917 show that eggs hatched from June 2 to June 15 inclusive. Field observations, while indicating that a few individuals may have hatched a week or more earlier, showed that the great majority of the eggs must have hatched during the first two weeks of June, confirming the insectary records. The hatching of larvæ in numbers occurred about three weeks before the grape blossoming period in 1917. The duration of the feeding period of most larvæ was from 6 to 7 weeks, averaging 46.12 days. Preparatory for pupation the larva secures itself by a loose web spun on a fold of a leaf or grape cluster. Two days are spent as prepupa and about 10 as pupa. The moth emerges in midsummer and deposits eggs which hatch the ensuing year.

It should be noted that the season of 1917 was a very late one, the grape blossoming period being about three weeks later than usual. It might be expected, therefore, that in a normal season the larvæ would hatch in considerable numbers in May and the earliest moths might even appear in June.

HABITS.

LARVAL HABITS.

As they hatch the larvæ eat out the micropyle and emerge from the egg, leaving the shell apparently as it was before. The newly hatched larvæ promptly migrate, scattering over the cane or vine on which the eggs happened to be placed. They are strictly solitary in habit and resent crowding. When two larvæ accidentally come in contact one is apt to strike viciously at the other, swinging its entire body in front of the prolegs like a whip and often knocking the intruder off the leaf. If both larvæ have a secure foothold a duel is apt to follow. In cages the writer has observed instances of cannibalism but this does not seem to be common. Because of this solitary habit seldom more than two or three are found on a single grape leaf. If crowded in cages the mortality is very high.

The grapevine looper progresses by the alternate measuring and looping movement characteristic of members of this group. It ex-

tends its long body to secure a foothold as far forward as possible and then looping the body upward brings forward its prolegs at the anal end of the body to secure footing immediately behind the thoracic legs. Among the earlier stages locomotion is very deliberate. The young larva precedes each forward extension of the body by raising the anterior part and swinging it in one direction or another as if to determine where the next step may safely be taken. In newly-hatched larvæ this preliminary movement is greatly exaggerated, and when a number of them migrate simultaneously along a cane they present a very ludicrous appearance, vigorously waving their long threadlike bodies to and fro before each looping movement.

The prolegs are the locomotor appendages most depended upon, and when the larva is stationary the thoracic legs are used but little. So muscular are the prolegs that one has difficulty in loosening their grasp upon a leaf-stem without causing injury to the larva itself. The larva may be made to fall if surprised when feeding, and when this is done, it seldom catches itself by a thread of silk as do the cankerworms.

When at rest or disturbed the older larvæ, in common with others of the group, have the habit of holding the body rigidly at an angle to the cane or stem on which they happen to be situated, depending entirely upon the prolegs for maintaining their hold. (Pl. II.) When in this position a larva may be mistaken for a grape tendril or leaf-stem, so that the habit is supposed to have some protective value. This habit is less characteristic of the younger larvæ, which when alarmed usually hold their body in a curved position instead of straight.

The dependence of the grapevine looper upon its prolegs for footing has modified its feeding habits, particularly in the earlier stages. Usually it grasps the edge of the leaf with its prolegs and extends its body over the upper surface toward the center of the leaf, eating the upper epidermis and parenchyma. As a result of this feeding habit a leaf attacked by one of these larvæ is marked by a series of whitish patches on the upper surface extending around the edge and about the same distance within. (Pl. III, B.) This characteristic location of the feeding marks readily distinguishes the work of this larva from that of any other pest of the grape with which the writer is familiar. However, if their position on the leaf is not taken into consideration the marks left by the small larvæ of the first instar may be mistaken for those of flea-beetles, while the large patches left by large larvæ might be mistaken for those of other grape-feeding Lepidoptera, as the eight-spotted forester (*Alypia octomaculata* Fab.) or beautiful wood nymph (*Euthisanotia grata* Fab.).

Larvæ of the fifth instar, and often of the fourth, feed at the edge of the leaf, stripping all but the stems and larger veins. (Pl. III, A.)

The time of this change in habit depends upon the texture of the leaf. It is in this stage that most of the damage is done.

The grapevine looper is largely crepuscular or nocturnal in its feeding habits. By day the majority of the larvæ hide on the underside of the leaves, holding to the midrib or larger leaf-veins. At this time of the day an inexperienced observer might have trouble finding many larvæ in a vineyard in which they were abundant. In the evening, however, just before dusk, practically all larvæ are feeding or moving from one leaf to another, and at this time they are readily found.

The larva does not make a cocoon, but spins a loose web (Pl. IV, B) which serves to hold the pupa in place. The pupal stage is passed in a leaf fold or in a grape cluster.

ADULT HABITS.

The moth is an active nocturnal flyer and is strongly attracted by electric lights. The writer has taken specimens at his desk lamp, which entered the room through an open window, and has frequently collected them at street lights. By day they rest on the underside of a leaf or cane and in this position have a curious habit of curling the abdomen dorsally so that it may nearly touch the dorsal surface of the head.

Oviposition occurs the day of emergence and may continue for two or three days, the length of life of the female. The number of eggs secured in cages from 22 females averaged 33.5 each. The moths oviposit readily in battery jars and are quite easily moved from one cage to another.

Eggs are deposited on their sides in more or less crescent-shaped rows of 8 to 12, the smaller ends being on the inner face of the crescent. Sometimes a second row is placed behind the first. In the vineyard they have been found only on the older vine growth and usually under strips of bark. In cages they may be placed almost anywhere, as on leaves and on the sides of the cages.

ECONOMIC IMPORTANCE.

The grapevine looper is a minor pest of the grapevine and as far as the writer has observed it has never caused serious injury except to grape arbors and garden vines. Of the minor pests which the writer has encountered in this region it is by far the most abundant, being present in much greater numbers than such well-known pests as the grapevine flea-beetle and the eight-spotted forester. It occurred in practically every vineyard, although in small numbers in those carefully sprayed for major pests. Its presence is usually unknown to the grower because of its habit of hiding by day and of the solitary habit which prevents conspicuous injury unless it is very abundant.

Even when partial stripping of the vines occurs it is usually attributed to some other cause. This insect should be regarded as a potential source of danger to the grape industry, which may at any time become destructive. It is also of importance in that its presence makes spraying to control the major pests of the vine more than ever advisable, since these measures incidentally hold it in check also.

CONTROL.

"Syringing" the vines with hellebore was the first remedial measure recommended (6) for the control of the grapevine looper. Since then the use of Paris green and arsenite of ammonia (18) have been recommended. These insecticides are now superseded by arsenate of lead, and this poison was used exclusively in experiments conducted at North East, Pa., during the season of 1917.

The amount of poison necessary to kill the grapevine looper was determined by spraying tests with various amounts. It was found that $1\frac{1}{2}$ pounds of arsenate of lead, powdered (equivalent to 3 pounds of paste) to 50 gallons of liquid was the minimum strength that would kill larvæ in all stages. Small proportions of poison would kill very small larvæ, but since there are apt to be some large larvæ on the vines before defoliation is serious enough to attract attention, it would seldom be advisable to use a weaker solution.

The liquid used may be water, or Bordeaux Mixture if it is desired to control fungus diseases at the same time. The time of application can best be determined by the presence of the caterpillars.

As previously indicated, a spray application directed primarily against the grapevine rootworm and the grape-berry moth, immediately after the grape blossoms have fallen, incidentally controls the grapevine looper. In spite of the fact that some of the looper larvæ are well developed at this time, the poison is sufficient to destroy all stages of the pest and prevent it from becoming abundant the following season. It should be remembered, then, that work properly done to control the rootworm and berry moth also controls the grapevine looper without additional expense.

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GRAPEVINE FLEA-BEETLES.

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INTRODUCTION.

The grapevine flea-beetle (*Altica chalybea* Ill.) is a grape pest which, in the period of its most destructive activity in early spring, eats out the swelling buds, causing severe injury in restricted localities. It is one of the best known and most widely distributed of the insect enemies of the grape. No other is the source of so many complaints to the Bureau of Entomology, and American entomological literature is full of references to it. In general its life history is well known, yet, in spite of this, occasional discrepancies occur in accounts of its life history that have never been reconciled with the usually recorded observations. These discrepancies are usually disposed of by attributing them to the variation of individual beetles.

A study of the life history of the grapevine flea-beetle was undertaken by the writer during the season of 1916 for the purpose of comparison with that of a smaller flea-beetle also attacking grape. A close similarity between the smaller beetle and the typical species was noted, but the differences, particularly in seasonal history and habits, were so well marked and so constant that the writer was

surprised when the smaller beetle was determined as "*Altica chalybea* Ill., small form." When it was noted that the seasonal history and habits of the typical flea-beetle conformed quite closely with those usually ascribed to it, particularly by Slingerland (19)¹ and Hartzell (23, 24), and that those of the "small form" coincided with the discrepancies mentioned above, the writer became of the opinion that two economic species had been masquerading under a single name. The existence of two species instead of one had long been suspected by Mr. E. A. Schwarz, who determined the reared material, but in the absence of biological data which would differentiate them he had not previously thought it advisable to erect a new species.

It is obvious that the confusion of two pests that are similar but have different seasonal histories may lead to a serious confusion in the application of remedial measures. It is, therefore, the purpose of this paper in the account of these two species, *Altica chalybea* Ill. and *A. woodsi*, herein described as new, to give particular attention to structure and habits by which they may be distinguished. Where each species must be treated separately, the typical grapevine flea-beetle, being the one generally known, is first considered, and the "small form" is then compared with it. The data presented are based on rearing records and field observations made at North East, Pa., during the seasons of 1916 and 1917 and miscellaneous field observations during the two seasons previous.²

HISTORY.

There are over 135 references to the grapevine flea-beetle in the literature of American economic entomology, a larger number of references than to any other American grape insect except the grapevine rootworm (*Fidia viticida* Walsh). Since 1859 there has been at least one reference to it each year except during the years 1866, 1873, and 1875. Most of these references no doubt apply to the typical form.

The grapevine flea-beetle was first described in 1807 by Illiger (1), who named it *Haltica chalybea*. It was again described by Le Conte (2) as *Galeruca janthina* and later by Thomas (3) as *Chrysomela vitivora*. Harris (5) in 1835 placed *C. vitivora* Thomas as a synonym of *H. chalybea* Ill., and the same year Herrick (4) showed that *G. janthina* Lec. was a synonym of the same species. In most of the recent literature relating to this insect it has been designated under the generic name *Haltica*. Woods (25) has recently shown that the original spelling *Altica* should be used instead of the amended form *Haltica*.

¹ Reference is made by number (italics) to "Literature cited," p. 26.

² During the season of 1916 the writer was assisted by Mr. James K. Primm. The writer is further indebted to Mr. J. H. Paine for the photographs used in Plates II and III and to Mr. H. K. Plank for the photograph used in Plate IV.

In the first account of the habits of the grapevine flea-beetle, Thomas recorded the destructiveness to grape buds by the adult, the feeding upon leaves by the larvæ, and the transformation through the pupal stage in the soil. Regarding these habits there has been practically no disagreement by succeeding authors. Conflicting statements have been frequently made, however, regarding the number of generations a year, the place of oviposition, and food plants.

Harris (6) outlined the seasonal history as follows: The emergence of adults from hibernation in April, followed by the development of immature stages, gives rise to another brood in July that are to pass through the ensuing winter. Harris called the brood of adults emerging in July a "second" brood, but he clearly meant that only one brood was produced annually. Harris's observations have been upheld by subsequent investigations, notably those of Slingerland (19) and Hartzell (23, 24), who have made the most thorough studies of the insect. Kirkpatrick (9), however, says that there are several generations annually, and the statement that there are two or more broods has been frequently made by subsequent writers. Lowe (20) states that there is a partial second brood in New York. Slingerland (19) offered a reason for inferring the existence of a second brood by quoting correspondence with Lowe in which the latter stated that he had found a beetle of this species ovipositing as late as July 15. At that time many newly transformed beetles were emerging while the overwintering beetles had disappeared before the last of June. Slingerland explained this unusual record of Lowe's as a record of an exceptionally late emergence of a tardy individual.

Riley (10) first stated that the eggs were deposited upon the leaves, and for nearly 30 years this was the generally accepted belief and was frequently copied by subsequent writers. Accompanying his statement of the place of oviposition he describes the eggs as "orange" and "like those of the potato beetle," making it seem probable that he had observed the eggs of some other insect. Comstock (12), in the most complete account of the insect up to that time, also stated that the eggs were found upon the leaves, either on the upper or lower side, and gave authority to his statement by accompanying it with an accurate description of the general appearance of the egg, and stated that it was "straw colored" and averaged 0.65 mm. in length. Marlatt (18) also referred to them as occurring on the leaves, but on the undersides only. Slingerland (19) stated that the eggs were usually found in groups under bud scales and strips of bark, and this observation was confirmed by Hartzell (23). Both investigators state that eggs may occasionally be found on the leaves. Hartzell describes the eggs as orange or saffron colored and with an average length of 1.03 mm.

The grapevine flea-beetle has been recorded as feeding on various plants, including the following: Grape (Thomas, 3), black alder (Harris, 7), plum and elm (Fitch, 8), Virginia creeper (Saunders, 11), apple and quince (MacMillan, 14), peach (Neal, 16), and blue beech (Schwarz, 17).

Of these food plants only three have been frequently listed, viz, the grape, the Virginia creeper, and the black alder. It was suggested by Lintner (13) that records of feeding upon black alder were probably due to a confusion of this species with *A. bimarginata*, the alder flea-beetle, which closely resembles *A. chalybea*. This view was confirmed, at least so far as Harris was concerned, by Slingerland (19), who found in Harris's entomological correspondence evidence that Harris's later studies convinced him that the alder flea-beetle and the grapevine flea-beetle are separate species. Hartzell (24) lists only cultivated grape of the Concord variety and the wild grape (*Vitis bicolor*) as food plants.

Slingerland (19) records a difference of opinion among growers as to what varieties of grapes are most seriously attacked by the grapevine flea-beetle, some correspondents stating that the flea-beetle preferred Concord foliage and others that it preferred the thin-leaved varieties.

In addition to the references designating the grapevine flea-beetle as *A. chalybea* Ill., Lugger (21) describes the habits of an insect which he calls "the lesser grapevine flea-beetle," and believed to be *A. ignita* Ill., the strawberry flea-beetle. He describes the habits as similar to those of *A. chalybea*, the only difference noted being that the former was little more than half the size of *A. chalybea*. It is quite possible that the insect referred to was the "small form" of the grapevine flea-beetle.

In discussing the "*ignita group*" of the genus *Altica*, Woods (26) mentions a beetle believed to be a new species collected on woodbine both in 1917 and in 1918, which is probably the lesser grapevine flea-beetle. He describes the salient characteristics of the adult and mentions that the eggs are deposited singly or by twos on the under surface of the leaves.

THE GRAPEVINE FLEA-BEETLE.

DESCRIPTION OF STAGES.

THE ADULT.

Pl. II, fig. 3.

The following is a copy of Horn's (15) description of the beetle:

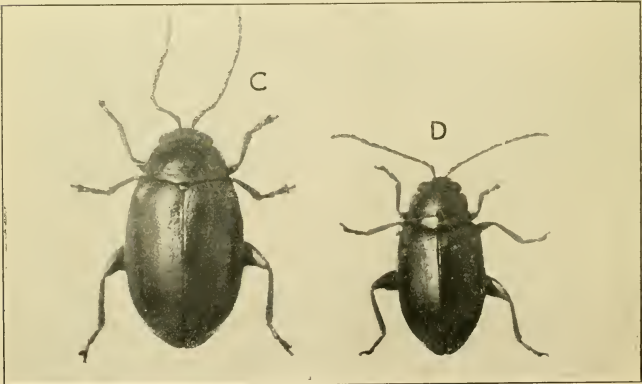
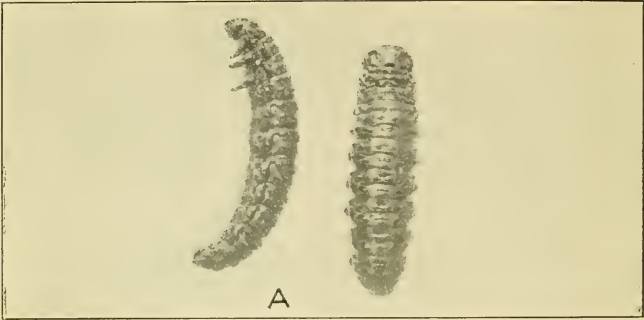
H. chalybea Illig.

Oval, of moderately robust facies, color usually metallic shining blue, rarely cupreous or greenish. Antennæ half as long as the body, piceous, the basal half with metallic lustre, joints 2-3-4 gradually longer. Head smooth, slightly rough-



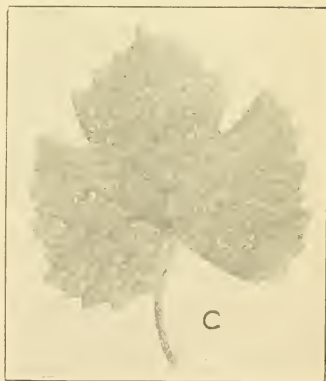
EGGS OF THE GRAPEVINE FLEA-BEETLES.

A, Eggs of *Altica chalybea* on grape cane under bark strip. B, Eggs of *Altica chalybea* on grape bud, bud scales removed. Bud shows feeding injury by adult beetle. C, Eggs of *Altica chalybea* on underside of grape leaf.



STAGES OF THE GRAPEVINE FLEA-BEETLES.

A, Mature larvæ of *Altica woodsi*. B, Pupæ of *Altica woodsi*. C, Adult of *Altica chalybea*.
D, Adult of *Altica woodsi*.



WORK OF GRAPEVINE FLEA-BEETLES.

A, Feeding marks of adult beetle of *Altica chalybea* on leaf of Concord grape. B, Larvæ and feeding marks of *Altica chalybea* on upper surface of grape leaf (thick-leaved variety). C, Feeding marks of adult beetle of *Altica chalybea* on grape leaf (thick-leaved variety).



WORK OF LESSER GRAPEVINE FLEA-BEETLE.
Feeding marks of larvæ and adults on grape (thin-leaved variety).

ened near the eyes, frontal carina rather acute, the tubercles small, oblique. Thorax a little more than half wider than long, narrowed in front, sides arcuate, margin narrow, slightly thickened in front, disc convex, the ante-basal impressed line rather deep and extending from margin to margin, surface with extremely minute scattered punctures. Elytra scarcely wider at base than the thorax, humeri rounded, umbone moderately prominent, smooth, limited within by a slight depression, surface sparsely punctate, nearly smooth near apex. Body beneath and legs blue-black, moderately shining, abdomen sparsely punctate. Length .16-.20 inch; 4-5 mm.

THE EGG.

Pl. I, A, B.

In general shape the egg is subcylindrical, with the ends rounded. The surface is roughly pitted, and on the surface opposite to the side of attachment is a twisted brownish strand about one-third the length of the egg. The color varies from a deep yellow to orange. Length 1.10 mm.; diameter 0.42 mm.

The size and color agree with the description by Hartzell (23) but differ from that of Comstock (12).

THE LARVA.

Similar to larva of *Altica woodsi*, Pl. II, A.

The larva is short and stout, convex dorsally and flattened ventrally, and is further characterized by a nearly hemispherical head, by short stout legs, and by an anus which functions as a locomotor organ. Each body segment is marked by a double series of chitinized plates or tubercles and the skin between these plates is dotted with minute wartlike excrescences. When the larva is newly hatched or molted it is yellow in color. Upon exposure to the air, however, the chitinized areas become shining black and as they fit closely together the larva itself becomes shining black. With growth the skin between the chitinized areas begins to show and when the larva is full grown the skin is so distended that a brownish yellow is the dominant color, the black being confined to the chitinized areas. The spiracles are located on the mesothoracic and first eight abdominal segments. The head and body plates are furnished with sparse, long setæ.

The arrangement of the body plates and setæ on the first seven abdominal segments is as follows: Dorsally each segment is furnished with two transverse rows of setiferous plates. The mid-dorsal plates are transversely elongate, the anterior one being slightly the longer, and are furnished with a seta on either side of the median line; on either side of each of these plates and above the spiracle are two smaller circular plates each bearing a single seta; below the spiracle is a prominent, longitudinal, compound tubercle, which roughly divides the dorsal and ventral aspects, bearing a pair of setæ, and below this is another tubercle also bearing two setæ; ventrally, near the anterior margin of the segment, there is one elongate, transverse plate crossing the median line and bearing one seta on either side; on the posterior half of the segment and at either side of the median plate is a small oval plate bearing two setæ.

On the first thoracic segment all dorsal plates are fused into one large plate, the prothoracic shield, which bears five pairs of setæ along the anterior margin, and three pairs in a row on the posterior margin; laterally there is one small tubercle bearing a single seta, and at the base of each coxa is a pair of tubercles each bearing a single seta; ventrally there is one large rectangular plate bearing an anterior and a posterior pair of setæ.

The second thoracic segment resembles the abdominal segments closely. The mid-dorsal plates are not continuous but are divided at the median line; on each side of the mid-dorsal plates is a single outer dorsal plate, the anterior one being quite

small and non-setiferous, the posterior one quite large and bearing two setæ; on each side below the outer dorsal plates is the laterally prominent compound tubercle which bears three setæ instead of two as on the abdominal segments; below the compound tubercle are two plates each bearing a single seta, the anterior one also bearing the mesothoracic spiracle; there is a pair of tubercles above each coxa, the posterior one of which bears a single seta; ventrally the arrangement of plates is similar to that of the first abdominal segment except that the posterior pair of plates bear only one seta each.

The third thoracic segment is like the second but without the spiracle.

The eighth abdominal segment is like the second, but with only one small dorsal plate on each side of the posterior mid-dorsal plate.

On the ninth thoracic segment the dorsal plates are fused into a single large one, the anal shield, which bears five pairs of setæ; ventrally there is a single elongate plate bearing two pairs of setæ.

The tenth abdominal segment is without plates or setæ.

Measurements: Width of head: First instar 0.32 mm.; second instar 0.51 mm. · third instar 0.74 mm. Average length of full grown larva 7.5 mm.

THE PUPA.

Similar to pupa of *Altica woodsi*, Pl. II, B.

In general appearance this pupa is similar to the pupa of other chrysomelid beetles, the dorsal line being strongly arcuate, the legs folded ventrally, bent so that the femora are directed away from the median line and the tibiæ toward it, the prothoracic and mesothoracic legs over the wings and the metathoracic legs under them.

Color bright yellow, appendages lighter. Antennal joints with a circlet of projections at the distal ends (four projections visible on each joint), especially conspicuous on the distal segments; elytra reaching the fifth abdominal segment, wings the sixth; spiracles borne on the mesothoracic and the first six abdominal segments; arrangement of setæ as follows: 3 pairs on head, 1 above clypeus, 1 on inner margin of the eyes, and 1 slightly above and between the eyes; on prothorax, 8 pairs; on mesothorax and metathorax, 2 pairs; on abdominal segments 1 to 8, 4 pairs in a row near the posterior dorsal margin; and on segment 9, 4 pairs around the anal hooks; 3 setæ on the distal end of each femur. Length 5 mm.

DISTRIBUTION.

The grapevine flea-beetle is found in the eastern half of the United States and in the Canadian Province of Ontario. In entomological literature and in the files of the Bureau of Entomology it has been recorded from the District of Columbia and from the following States: Massachusetts, Vermont, Connecticut, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, North Carolina, Georgia, Florida, Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, Arkansas, Texas, Kansas, Nebraska, Colorado, and New Mexico. Some of these records may refer to the "small form."

FOOD PLANTS.

A list of food plants recorded in the literature of the species is given under history. The writer has collected it only on cultivated grapes (*Vitis* spp.), on various species of the wild grape (*Vitis* spp.), and on Virginia creeper (*Parthenocissus quinquefolia*).

HABITS.

The beetle emerges from hibernation in the spring at the time of the swelling of the grape buds, which it attacks voraciously, boring into the sides of the buds and eating out the tender parts. (Pl. I, B.) When the shoots begin to expand it eats large holes in the leaves (Pl. III, A), and often attacks the tender stems. The beetle is most voracious when newly emerged from hibernation and at that time can do an immense amount of damage.

Eggs are usually deposited on their sides, in groups, under bud scales or strips of bark, as described by Slingerland (19) and Hartzell (23 and 24). Occasionally they are placed on leaves on either the upper or the lower side.

The larvæ feed on either the upper or lower surface of thin-leaved varieties of cultivated and wild grapes, eating out large irregular holes, and often stripping out all of the leaf tissue except the leaf veins. On Concord or similar types of leaves they feed on the upper surface, leaving as feeding marks long, chain-like, whitish patches (Pl. III, B).

During the feeding period the larva molts twice. Upon becoming fully fed it burrows into the ground and forms a pupal cell a fraction of an inch below the surface. A few days are passed in the pupal cell, the prepupal period, preparatory for pupation. At the close of the pupal stage, after eclosion, the adult does not emerge at once, but remains in the cell until it is hardened and fully colored. Following emergence the beetle feeds sparingly until it goes into winter quarters. None of the specimens under observation during either season showed any tendency to copulate or oviposit during the period between transformation to the adult stage and hibernation.¹

All stages of the beetles' activity are greatly influenced by changes in temperature. Both adults and larvæ feed more voraciously on warm days than in cold weather and on the cold days of early spring the beetles even appear to return to winter quarters. Hatching of eggs and molting of larvæ occur in the greatest numbers during the warmest part of the day.

LIFE HISTORY.

REARING METHODS.

The rearing methods used for the two species of flea-beetles were practically identical. Oviposition was secured from adults kept in battery jars or sleeve cages on grape shoots. Larvæ were reared in

¹ In addition to the insects native to the Erie-Chautauqua grape belt, upon which the foregoing account of habits and seasonal history and the following of life history are based, the writer received beetles from French Creek, W. Va., collected by Mr. Fred E. Brooks, and from Arlington, Va., collected by Mr. E. R. Selkroge, during the spring of 1917. These beetles and their offspring were reared in the insectary at North East, Pa., and their habits, seasonal history, and transformations agreed in detail with those of the native insects recorded herein.

1 by 4 inch vials. Transformations from the prepupal and pupal stages to the adult were passed in vials of the same size partially filled with earth. To determine the duration of each of these periods in the ground two methods were employed, as follows:

The first was to place a vial five-eighths of an inch in diameter inside of a vial 1 inch in diameter, filling the space between the two with earth. In this narrow space mature larvæ were placed and most of them were forced to form their pupal cells next to the glass surface, where their transformations could be observed readily. The outer vial was covered with black paper, which was removed only when observations were being made. For convenience of identification each cell was marked with a wax pencil. This method was faulty, because of the difficulty of maintaining the normal soil moisture in so thin a layer.

It was later learned that by pressing the earth in the middle of the vial, leaving the earth at the sides comparatively loose, about half of the larvæ would form pupal cells along the sides of the glass. It was necessary, of course, for success with this method, as with the former, that the vials be wrapped with black paper. This method was most used in 1917.

TABLE I.—Feeding period of third larval stage of *A. chalybea*, North East, Pa., 1916.

Number of larvæ.	Duration of period.
	<i>Days.</i>
18	6
29	7
17	8
15	9
6	10
2	11
2	13
189	7.75

¹ Total. ² Weighted average.

These methods of observing transformation in the ground were developed in the latter part of 1916 and the data on these transformations secured during that season are very meager. Hence records for the prepupal, pupal, and callow adult stages of both species are given only for 1917.

Detailed life-history studies of the typical grapevine flea-beetle did not begin in 1916 until the majority of the larvæ were at least half grown, since they were undertaken for comparison with the more common "small form." Accordingly rearing records cited below begin with the third larval stage in 1916.

DURATION OF FEEDING PERIOD OF THIRD STAGE IN 1916.

The duration of the feeding period of the third larval stage varied from 6 to 13 days, with an average of 7.75 days, as shown in Table I. The period covered by these records extended from June 12 to July 8.

DURATION OF PERIOD IN GROUND.

The duration of the period in the ground of 87 individuals reared varied from 15 to 24 days, with an average of 20.71 days.

The period covered by records of larvæ in the soil extended from June 19, when the first larvæ entered the ground, to July 27, when the latest adults emerged. The variation in duration of this period is shown in Table II.

EMERGENCE FROM HIBERNATION AND OVIPOSITION IN 1917.

The earliest record of adult emergence is May 11, at which time grape buds were swelling. Eggs were first found May 18. Adult beetles were found on grapevines until the latter part of June, when they disappeared altogether.

TABLE II.—*Period in ground of A. chalybea, North East, Pa., 1916.*

Number of individuals.	Duration of period.
	<i>Days.</i>
2	15
1	16
4	17
7	18
10	19
16	20
8	21
20	22
12	23
7	24
187	220.71

INCUBATION PERIOD IN 1917.

The duration of the incubation period in 1917 (see Table III) varied from 13 to 21 days, with an average of 15.18 days, as shown in Table III. The period covered by records on the incubation period extended from May 26 to June 28.

LARVAL FEEDING PERIOD.

The duration of the larval feeding period of 46 individuals of *Altica chalybea* reared to adults varied from 19 to 33 days with an average of 24.26 days. The period covered by records of feeding larvae extended from June 4, the earliest date of hatching, to July 20, the latest date, when larvæ entered the ground. Complete data on the larval feeding period are given in Table IV.

¹ Total. ² Weighted average.

TABLE III.—*Incubation period of A. chalybea, North East, Pa., 1917.*

Date of oviposition.	Date of hatching.	Number of eggs.	Duration of period.	Date of oviposition.	Date of hatching.	Number of eggs.	Duration of period.
			<i>Days.</i>				<i>Days.</i>
May 26	June 14	6	19	June 2	June 15	10	13
26	16	6	21	2	16	4	14
29	12	1	14	2	17	5	15
31	13	4	13	2	18	2	16
31	14	4	14	2	19	2	17
31	15	2	15	4	19	25	15
31	16	2	16	4	20	17	16
June 1	14	12	13	13	28	1	15
1	15	4	14				
1	16	1	15				
						¹ 108	² 15.18

¹ Total.

² Weighted average.

DURATION OF FIRST LARVAL STAGE.

The duration of the first stage, of 68 larvæ reared, varied from 4 to 14 days with an average of 8.74 days, as is shown in Table V. The total period covered by records on larvæ in this stage extended from June 4 to July 2.

DURATION OF CALLOW PERIOD.

The duration of the callow period of the adult stage varied from 1 to 4 days with an average of 2 days. The records are summarized in Table XI. Records on this period extended from July 24 to August 4.

SUMMARY.

There is only one generation annually, winter being passed in the adult stage. Beetles emerge from hibernation when the grape buds are swelling and oviposition begins soon after and continues until about the middle of June, a few days before the latest adults disappear.

The average duration of the incubation period in 1917 was 15.18 days.

The larval feeding period averaged 24.26 days in 1917. Records of feeding larvæ began June 4 and continued until July 20. The duration of the different larval stages was as follows: First stage, 8.74 days in 1917; second stage, 6.95 days in 1917; third stage, 7.75 days in 1916 and 8.53 days in 1917.

The duration of the period in the ground averaged 20.71 days in 1916 and 19.24 days in 1917. Records taken during the two years on the transformations of this beetle while in the ground extended from June 22 to August 4. The duration of the different stages in the ground in 1917 was as follows: Prepupa 9.17 days, pupa 8.47 days, callow adult 2 days.

TABLE VII.—Feeding period of third larval stage, *A. chalybea*, North East, Pa., 1917.

Number of larvæ.	Duration of stage.
	<i>Days.</i>
1	5
6	6
10	7
5	8
10	9
11	10
2	12
2	13
¹ 47	² 8.53

¹ Total.

² Weighted average.

TABLE VI.—Second larval stage of *A. chalybea*, North East, Pa., 1917.

Number of larvæ.	Duration of stage.
	<i>Days.</i>
3	5
18	6
26	7
8	8
3	9
1	10
1	11
¹ 60	² 6.95

¹ Total.

² Weighted average.

THE LESSER GRAPEVINE FLEA-BEETLE.

(*Altica woodsi* n. sp.)

The specific name *A. woodsi* is given in recognition of Mr. Woods's recent systematic and biological studies of members of the genus *Altica* (25, 26), and because he is the first to record what is

probably this insect as a new species.

DESCRIPTION OF STAGES.

THE ADULT.

Pl. II, D.

This beetle is similar to *Altica chalybea*, from which it may be distinguished as follows: Color metallic green, rarely with purple or olivaceous reflections; antennal joint 3 equal in length to joint 4; average length 3.05 mm., varying from 2.43 to 3.05 mm.

Date of entering ground.	Date of emergence.	Number of individuals.	Duration of period.	Date of entering ground.	Date of emergence.	Number of individuals.	Duration of period.
June 28	July 23	1	<i>Days.</i> 25	July 11	July 30	2	19
July 2	27	3	25	11	Aug. 1	1	21
4	26	2	22	13	July 31	2	18
5	26	1	21	13	Aug. 2	2	20
7	27	1	20	14	Aug. 2	3	19
8	27	4	19	15	July 31	1	16
8	28	3	18	15	Aug. 1	1	17
9	30	1	21	15	3	1	19
10	28	1	18	17	1	3	15
10	29	1	19	17	4	1	18
10	30	3	20				
11	28	4	17			1 42	2 19, 24

² Weighted average.

Type.—Cat. No. 22290, U. S. National Museum.

Pl. I. C.

Color straw yellow. Brownish strand much larger proportionately than that of the "large form," about one-half the length of the egg.

TABLE IX.—*Prepupal period of* This size and color are as described by Comstock (12).

The size and color are as described by Comstock (12).

Pl. II, A.

Similar to the larva of the "large form" (*A. chalybea*) but much smaller. The chitinized areas are smaller proportionately and the fully fed larva is distinctly yellow without the brownish color element. The setae on the ventral prothoracic segment are wanting. Width of head: First instar from 0.292 to 0.312 mm., average 0.306 mm.; second instar from 0.435 to 0.458 mm., average 0.453 mm.; third instar 0.577 to 0.624 mm., average 0.612 mm. Average length of full grown larva 5 mm.

² Weighted average.

Pl. II, B.

TABLE X.—*Pupal stage of A. chalybea, North East, Pa., 1917.*

Number of pupæ.	Duration of period.
	<i>Days.</i>
4	7
4	8
6	9
3	10
1 17	2 8.47

² Weighted average.

Number of individuals.	Duration of period.
4	<i>Days.</i> 1
13	2
2	3
1	4
1 20	2 2

²Weighted average.

DISTRIBUTION.

The writer has collected this species in the vicinity of North East and Moorheadville, Pa., and has observed it at Niagara Falls, N. Y.

FOOD PLANTS.

The grape (*Vitis* spp.), both wild and cultivated, and the Virginia creeper (*Parthenocissus quinquefolia*) are food plants of both the larva and the adult of this beetle. Of the cultivated grapes the larva flourishes on thin-leaved varieties like the Delaware but does not favor thick-leaved sorts like the Concord. Larvæ were frequently found on Concord grapes in the field but the majority of the newly hatched larvæ placed on Concord leaves in cages failed to pass the first instar. After this instar was passed little difficulty was experienced in carrying them to the adult stage.

Grape growers, mentioned by Slingerland (19), who stated that thin-leaved varieties of grapes were preferred by the grapevine flea-beetle probably had this insect to deal with instead of the typical species.

HABITS.

When the adult emerges from hibernation in the spring it attacks grape leaves which are already expanded. On the leaves of favored hosts it feeds on the lower sides, riddling them with holes. (Pl. IV.) On Concord and other similar varieties it feeds on the upper surface, pitting it with short irregular feeding marks but not eating through the leaf. (Pl. III, C.) Like the typical species it feeds much more voraciously at this time than later. It also has the same habit of feigning death when alarmed.

Eggs are usually placed singly on the underside of grape leaves, along the veins. (Pl. I, C.) Occasionally two or three are together and very rarely they are on the upper surface of the leaves. This is strikingly different from the place of oviposition and arrangement of eggs described by Slingerland (19) and Hartzell (24), but agrees with the records of Comstock (12), Marlatt (18), and others.

Like the adult the larva usually feeds on the underside of thin-leaved varieties of grapes and the Virginia creeper. A newly hatched larva usually begins at the side of a leaf vein and bores upward. When leaves are first attacked a series of small holes appears along the leaf veins, producing a characteristic marking which need not be mistaken for the feeding injury of any other insect. (Pl. IV.) After feeding has progressed for some time the holes are larger and are scattered over the leaf, which may become entirely skeletonized. The larvæ do not move readily from one leaf to another and consequently the leaves on one part of the vine may be completely riddled while those near by are untouched.

DURATION OF FIRST LARVAL STAGE.

The duration of the first stage, of 74 larvæ reared, varied from 3 to 9 days with an average of 6.16 days, as shown in Table XIV.

TABLE XIV.—*First larval stage of A. woodsi, North East, Pa., 1916.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
1	3
1	4
17	5
32	6
16	7
3	8
4	9
¹ 74	² 6.16

¹ Total.

² Weighted average.

TABLE XV.—*Second larval stage of A. woodsi, North East, Pa., 1916.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
4	4
18	5
15	6
11	7
14	8
2	10
1	15
¹ 65	² 6.46

¹ Total.

² Weighted average.

The records in this stage cover a period from June 18, the earliest recorded date of hatching, to July 15, the latest recorded date of passing the first molt.

DURATION OF THE SECOND LARVAL STAGE.

The duration of the second larval stage varied from 4 to 15 days with an average of 6.46 days, as shown in Table XV. The total period covered by records on larvæ of this stage extended from June 25 to July 21.

TABLE XVI.—*Feeding period of third larval stage of A. woodsi, North East, Pa., 1916.*

Number of larvæ.	Duration of period.
	<i>Days.</i>
2	3
2	4
9	5
12	6
7	7
1	8
4	9
3	10
1	13
¹ 41	² 6.51

¹ Total.

² Weighted average.

DURATION OF FEEDING PERIOD OF THIRD LARVAL STAGE, NORTH EAST, PA., 1916.

The duration of the feeding period of the third stage of 41 larvæ varied from 3 to 13 days, with an average of 6.51 days, as shown in Table XVI. The total period covered by records of larvæ in this stage extended from July 1 to 26.

DURATION OF PERIOD IN GROUND.

The period in the ground includes the prepupal period, which is the latter part of the third stage, the pupal period, and the early part of the adult stage before emergence from the pupal cell. Fifty-three individuals were carried through this period. The minimum time required was 14 days, the maximum 21 days, and the average of 16.15 days. The period covered by these records extended from July 7, when the first larva entered the ground, until August 29, when the last adult emerged. These data are given in full in Table XVII.

TABLE XVII.—*Time and duration of immature stages in the ground of Altica woodsi, North East, Pa., 1916.*

Date of entering ground.	Date of emergence.	Number of individuals.	Duration of period.	Date of entering ground.	Date of emergence.	Number of individuals.	Duration of period.
			<i>Days.</i>				<i>Days.</i>
July 7	July 24	1	17	July 21	Aug. 7	1	17
10	24	7	14	24	7	1	14
10	25	2	15	Aug. 1	16	1	15
10	26	1	16	1	17	1	16
15	29	3	14	3	19	3	16
16	Aug. 5	3	20	6	21	3	15
17	July 31	2	14	6	25	1	19
17	Aug. 2	1	16	8	25	1	17
18	2	1	15	8	26	1	18
18	6	7	19	8	29	1	21
19	2	1	14				
21	5	3	15				
21	6	7	16				
						¹ 53	² 16.15

¹ Total.² Weighted average.

EMERGENCE FROM HIBERNATION, 1917.

A few beetles emerged from hibernation in the latter part of May, but they were not abundant until the early part of June. The first specimens were collected May 19 on wild grape, when Concord grape shoots were about 8 inches long and the flower buds were showing.

TABLE XVIII.—*Incubation period of A. woodsi, North East, Pa. 1917.*

Date of oviposition.	Date of hatching.	Number of eggs.	Duration of period.
			<i>Days.</i>
July 19	July 2	16	13
19	3	8	14
20	3	6	13
20	4	17	14
21	5	2	14
21	6	2	15
22	6	12	14
23	7	8	14
		¹ 71	² 13.72

¹ Total.² Weighted average.

None were collected on cultivated grapes until June 3, when they were common. They increased in numbers until about June 9.

OVIPOSITION.

Oviposition began about 18 days after the emergence of the earliest adults and continued until the latter part of

July. The latest recorded date of oviposition was July 26. The longest recorded period of oviposition for a single female was 41 days, from June 12 to July 23; this beetle deposited eggs on 17 days during that period. The number of eggs deposited by four isolated females varied from 37 to 181, with an average of 102.5 eggs each. Thirty-one eggs is the largest number deposited on a single day.

INCUBATION.

The duration of the incubation period of 71 eggs varied from 13 to 15 days, with an average of 13.72 days, as shown in Table XVIII

TIME AND DURATION OF THE LARVAL FEEDING PERIOD.

The duration of the feeding period of 190 larvæ varied from 15 to 23 days with an average of 18.59 days. The period covered by records on feeding larvæ extended from June 26 to July 26. Complete data on time and duration of this period are given in Table XIX.

TABLE XIX.—*Time and duration of larval feeding period of A. woodsi, North East, Pa., 1917.*

Date of hatching.	Date of entering ground.	Number of larvæ.	Duration of period.	Date of hatching.	Date of entering ground.	Number of larvæ.	Duration of period.
			<i>Days.</i>				<i>Days.</i>
June 26	July 14	5	18	July 4	July 25	2	21
26	15	6	19	5	22	26	17
26	16	1	20	5	23	7	18
26	17	11	21	5	24	2	19
July 2	20	6	18	5	25	4	20
2	21	7	19	6	23	3	17
3	21	9	18	6	25	7	19
3	22	15	19	7	23	6	16
3	23	9	20	7	24	3	17
3	24	3	21	7	25	1	18
3	25	1	22	9	24	2	15
3	26	1	23	9	25	4	17
4	22	9	18	9	26	1	18
4	23	34	19				
4	24	5	20				
						¹ 190	² 18.59

¹ Total.

² Weighted average.

DURATION OF THE FIRST LARVAL STAGE.

The duration of the first larval stage was from 4 to 11 days with an average of 6.35 days, as shown in Table XX. The period covered by records on larvæ of this stage extended from June 26, the earliest recorded date of hatching, to July 15, the latest recorded date of passing the first molt.

TABLE XX.—*First larval stage of A. woodsi, North East, Pa., 1916.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
2	4
29	5
85	6
74	7
39	8
4	9
3	10
1	11
¹ 237	² 6.35

¹ Total.

² Weighted average.

DURATION OF SECOND LARVAL STAGE.

The duration of the second stage of 209 larvæ was from 4 to 9 days with an average of 6 days, as shown in Table XXI. The total period covered by records on larvæ of this stage extended from July 1 to July 21.

DURATION OF FEEDING PERIOD OF THIRD LARVAL STAGE.

The duration of the feeding period of the third larval stage of 189 larvæ varied from 4 to 9 days with an average of 6.62 days, as shown in Table XXII. The total period covered by records of larvæ in this stage is from July 6 to July 26.

TIME AND DURATION OF PERIOD IN GROUND.

The duration of the period in the ground of 115 individuals reared varied from 12 to 17 days with an average of 14.50 days. This period is covered by records extending from July 14 to August 11. The data on time and duration of this period are given in full in Table XXIII.

TABLE XXI.—*Second larval stage of A. woodsi, North East, Pa., 1918.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
6	4
41	5
113	6
45	7
3	8
1	9
¹ 209	² 6.00

¹ Total. ² Weighted average.

TABLE XXII.—*Feeding period of third larval stage of A. woodsi, North East, Pa., 1918.*

Number of larvæ.	Duration of stage.
	<i>Days.</i>
4	4
72	5
69	6
12	7
18	8
14	9
¹ 189	² 6.62

¹ Total. ² Weighted average.

DURATION OF PREPUPAL STAGE.

The prepupal period of 57 larvæ recorded varied from 4 to 7 days, with an average of 4.68 days, as shown by Table XXIV. The total period covered by records on the prepupa extended from July 14 to August 1.

TABLE XXIII.—*Time and duration of period in ground of A. woodsi, North East, Pa., 1917.*

Date of entering ground.	Date of emergence.	Number of individuals.	Duration of period.	Date of entering ground.	Date of emergence.	Number of individuals.	Duration of period.
			<i>Days.</i>				<i>Days.</i>
July 14	July 29	1	15	July 22	Aug. 6	11	15
14	30	4	16	22	7	3	16
15	30	4	15	22	8	2	17
15	31	2	16	23	4	1	12
16	30	1	14	23	6	6	14
17	31	2	13	23	7	10	15
17	30	7	14	24	7	3	14
17	Aug. 1	2	15	24	8	5	15
20	2	2	13	25	6	1	12
20	3	1	14	25	8	1	14
20	4	1	15	25	9	6	15
21	2	1	12	25	10	1	16
21	3	4	13	25	11	1	17
21	4	8	14	26	9	1	14
21	5	5	15	26	11	1	16
22	4	4	13				
22	5	13	14				
						¹ 115	² 14.50

¹ Total.

² Weighted average.

DURATION OF PUPAL STAGE.

The pupal period of 45 individuals recorded varied from 6 to 9 days, with an average of 7.24 days, as shown by Table XXV. The total period covered by records on the pupa extended from July 20 to August 7.

DURATION OF CALLOW PERIOD.

The duration of the callow period of the adult stage, or the period after transformation of the pupa to adult and before its emergence from the ground, was recorded for 48 individuals. It varied from 1 to 4 days, with an average of 2.19 days, as shown in Table XXVI. The period covered by these records extended from July 28 to August 11.

SUMMARY.

The seasonal history of the lesser grapevine flea-beetle is similar in general to that of the larger species, but it is later throughout. There is a single generation annually, winter being passed in the adult stage. Beetles emerge from hibernation in the latter part of May or early June, some time after the grape shoots have expanded, or about three weeks later than the typical species. Oviposition begins early in June and continues until the latter part of July, when the last adults disappear.

The average duration of the incubation period was 12.82 days in 1916 and 13.72 days in 1917, slightly less than that of the larger species, but this difference may be accounted for by the fact that these incubation records were taken later in the season, when the temperature was higher.

TABLE XXV.—*Duration of pupal stage of A. woodsi, North East, Pa., 1917.*

Number of pupæ.	Duration of stage.
	<i>Days.</i>
10	6
16	7
17	8
2	9
¹ 45	² 7.24

¹ Total. ² Weighted average.

TABLE XXVI.—*Callow period of adult stage of A. woodsi, North East, Pa., 1917.*

Number of individuals.	Duration of period.
	<i>Days.</i>
12	1
19	2
13	3
4	4
¹ 48	² 2.19

¹ Total. ² Weighted average.

Larvæ are found on the vines in midsummer, the records of collection extending from June 18 to August 8. The average duration of the larval feeding period was 18.71 days in 1916 and 18.59 days in 1917, or about one-fourth shorter than that of the "large form." The duration of the three larval stages was as follows: First stage, 6.16 days in 1916 and 6.35 days in 1917; second stage, 6.46 days in 1916 and 6 days in 1917; third stage, 6.51 days in 1916 and 6.62 days in 1917.

TABLE XXIV.—*Prepupal stage of A. woodsi, North East, Pa., 1917.*

Number of individuals.	Duration of period.
	<i>Days.</i>
29	4
19	5
7	6
2	7
¹ 57	² 4.68

¹ Total.

² Weighted average.

The maximum limits of records of individuals transforming in the ground were from July 7 to August 29. The duration of this period of transformation averaged 16.15 days in 1916 and 14.50 days in 1917, or about 5 days less in each season than those required for the "large form." The average duration of the different stages in the ground was as follows: Prepupa 4.68 days, pupa 7.24 days, callow adult 2.19 days.

After emergence from the ground the beetles feed until late in autumn and then go into hibernation. A comparison of the foregoing with the seasonal history of the typical grapevine flea-beetle shows that the lesser species appears in the vineyard about three weeks later than the other and continues later throughout the season. The typical species disappeared from vineyards at the season indicated by Slingerland (19), while the "small form" was present at the time that the "tardy individual," referred to by him, was found ovipositing, some time after the overwintering adults of the typical species had disappeared. Following Slingerland's suggestion a little further, it seems probable to the writer that the collection of beetles of the "small form," if confused with the typical species, could easily give rise to the two-brood hypothesis.

This comparison also shows that the lesser grapevine flea-beetle is more rapid in its development, particularly in the larval and prepupal stages. This more rapid development can not be attributed to any extent to the fact that the larvæ appear later in the season, for even late individuals of the "large form" reared at the same time as the early individuals of the "small form" required more time for their metamorphosis.

ECONOMIC IMPORTANCE.

The grapevine flea-beetle, according to all accounts, has been one of the most destructive of insects to the grape industry. Slingerland (19) wrote in 1898 that for several years previous it had done more damage to vineyards in New York than all other grape insects combined. Emerging from hibernation at the time when the grape buds are swelling, a single beetle, by eating out comparatively few buds, destroys as many shoots and a much larger number of clusters. If the injury is repeated, according to Quaintance and Shear (22), the vines themselves may be weakened or killed. Feeding after the grapes come into leaf, either by the adults or by the larvæ, is less destructive.

Compared with its larger relative, the lesser grapevine flea-beetle is greatly limited in its possibilities for destructiveness, because the adult does not emerge from hibernation early enough to attack the buds, but, like the larva, is strictly a leaf feeder. In spite of this limitation, however, where it occurs in large numbers it can cause

considerable damage by its skeletonizing of the foliage. In one instance the writer has noted the killing of 1-year-old vines of the Delaware variety by repeated defoliation. Not the least important economic consideration with regard to this beetle is the possibility of its being mistaken for the larger form and the consequent confusion of remedial measures.

In spite of their potential ability to injure the grape industry, during the years of the writer's residence in the Erie-Chautauqua grape belt (1914-1917) both of these insects were of minor importance. Such infestations as were observed were confined to vines on the borders of vineyards adjacent to woodlands in which there were heavy growths of wild grapes.

The grapevine flea-beetle, like a number of related insects, is given to sporadic outbreaks of destructiveness followed by periods of comparatively little economic importance. This is well illustrated by the periodic receipt of complaints by the Bureau of Entomology. Based on this source of information, it appears that there have been three distinct extensive outbreaks in recent years: One in 1892 in Michigan, Missouri, Iowa, and Kansas, one during 1894 and 1895 in New York, and one in 1911 in Maryland, Virginia, and the District of Columbia. Requests for information regarding this insect have been received in practically all of the intervening years, but they have been comparatively few in number and much more local. Slingerland (19), writing in 1898, also records a serious period of destructiveness in New York for several years previous. On the other hand, 17 years later Hartzell (24) estimated that in the Erie-Chautauqua grape region less than 1 per cent of the area was infested.

It is probable that the period when the writer's observations were made represented a low tide in the abundance of these beetles, due to natural checks, as they were totally absent not only in vineyards where measures to destroy them might be taken, but also from the majority of neglected vineyards and from most growths of wild grapes. But aside from the natural causes there are two other factors which have contributed to a permanent change in the economic status of this pest. Poison sprays, applied primarily to destroy the grapevine rootworm (*Fidia viticida* Walsh) and the grape-berry moth (*Polychrosis viteana* Clem.), readily destroy the flea-beetle larvæ feeding on the leaves at that time and may destroy many of the adults of the lesser flea-beetle which are also still in the vineyards. Up-to-date methods of tillage under vines, which break open the pupal cells, are also a contributing factor. These two factors make it difficult for beetles to reproduce in well-cared-for vineyards and limit them to neglected vineyards and wild vines. Sporadic outbreaks may nevertheless be expected in vineyards adjacent to favorable breeding places, and these may be very severe locally.

PREDATORY ENEMIES.

The natural causes responsible for the periods of comparative unimportance of the flea-beetles at the time they were under observation were undetermined. Three species of carabid beetles and one of ants were found predatory on both flea-beetles, although none of the carabids was found in large numbers. No species of parasites has been reared by the writer.

Lebia viridis Say,¹ the most common carabid, was closely associated with both species of flea-beetles. It feeds upon the eggs, larvæ, and pupæ of both species. This *Lebia*, although classed as a ground-beetle, is largely arboreal. It was found in leaf mold under wild grapevines, where flea-beetles were pupating in large numbers, but more frequently on grape leaves, both in vineyards and on wild vines. One specimen was taken on a wild grapevine over 15 feet above the ground. In spite of their individual voracity, as these beetles always occurred singly and were never found in large numbers, they were not regarded as of sufficient importance to hold the grapevine flea-beetles in check.

The earliest recorded collection of *Lebia viridis* was May 22, in 1917. This beetle was found feeding upon eggs under strips of bark on grape canes. No more were found until June 22, when larvæ of the typical flea-beetle were quite common on the vines. After this time until the first of August *Lebia viridis* was fairly numerous. The latest record of collection was September 11, in 1916, after all of the immature stages of the flea-beetles had transformed.

This carabid is steel blue in color and about the size of the typical grapevine flea-beetle, with which it might be confused by a casual observer. It is probably the enemy of the flea-beetle referred to by Hartzell (24), which he describes as a "carabid closely resembling the adult flea-beetle in size and color."

Lebia ornata Lec.¹ and *Harpalus erythropus* Dej.¹ were found in very small numbers in leaf mold under wild grapevines, and fed upon pupæ and prepupæ of the flea-beetles in confinement.

A brown ant, *Myrmica scabrinodis* Nyl., subsp. *schenchi* Emery, var. *emeryana* Forel,² destroyed a large amount of larval and pupal material that was intended for use in rearing work. Full-grown larvæ had been placed in earth in flowerpots partially buried in the insectary yard. A few days later ants were found carrying larvæ and pupæ from these pupation quarters.

The Biological Survey has found grapevine flea-beetles in the stomachs of the following birds: Bobwhite (*Colinus virginianus*), meadowlark (*Sturnella magna*), Cape May warbler (*Dendroica tigrina*), red-eyed vireo (*Vireosylva olivacea*), white-eyed vireo (*Vireo griseus*),

¹ Determined by Mr. E. A. Schwarz.

² Determined by Dr. W. M. Wheeler.

Philadelphia vireo (*Vireosylva philadelphica*), Carolina wren (*Thryothorus ludovicianus*), and bluebird (*Sialia sialis*).

METHODS OF CONTROL.

As previously stated, no extensive infestation of either species of flea-beetle came under the writer's observation in the Erie-Chautauqua grape belt, and those infestations that did occur were confined to vines at the ends of rows or the edges of vineyards.¹ In such situations hand-picking the beetles was the best means of control. The effect of this method is immediate, which is very desirable against so voracious an insect, against which arsenical sprays act comparatively slowly. On small areas in a corner or at the edge it is also cheaper than the employment of a power sprayer, which must be drawn the entire length of each row, of which only a small part may be infested. Had an extensive infestation occurred, spraying would have been resorted to, but as none was present no spraying experiments were conducted.

The application of a spray mixture containing 3 pounds of arsenate of lead paste (1½ pounds, powdered) to 50 gallons of Bordeaux mixture is usually recommended for the control of the typical species. One of the recent investigators, Hartzell (24), states that this mixture protects the vines from severe injury because it is repellent to the beetles and disperses them over the vineyard, but that it does not kill them. To kill the beetles he has found that a high dosage of arsenate of lead, not less than 4 pounds paste (2 pounds, powdered) to 50 gallons of water, is most effective. This high dosage is necessary to kill the beetles quickly before much damage is done, because of their voracity and resistance to poison. He also states that the effectiveness of the poison is much increased by the addition of one-half gallon of molasses to the foregoing mixture. The addition of molasses because of its solubility has the disadvantage, however, of making the poison likely to be washed off by rains. Owing to the frequency of rains at this season of the year this is a very serious disadvantage. *Molasses should not be added to a spray solution containing Bordeaux mixture, or burning of the foliage is apt to result.* The time of application should be on the first warm day when the grape buds are swelling, or as soon as the beetles appear.

The difficulty of destroying the adults makes it important that these pests be not allowed to reproduce in a vineyard. The

¹ After this paper had gone to press, in the spring of 1920, the writer's attention was called to extensive destructiveness by *A. chalybea* at Neosho, Mo., by Mr. F. W. Faurot, director of the Missouri State Fruit Experiment Station at Mountain Grove, Mo. It was stated that the greater part of the crop in a number of vineyards had been destroyed by the activities of this beetle during the previous season. In 1920 it was apparently much the most destructive grape insect of the region. Spraying experiments for the control of beetles emerging from hibernation were conducted by Mr. A. J. Ackerman and the writer, in cooperation with the Missouri Fruit Experiment Station. Arsenate of lead at the rate of 3 pounds (powdered) to 50 gallons of water gave fair control, and this dosage was much more effective than one of 2 pounds to 50 gallons of water.

immature stages are very susceptible to remedial measures, and their destruction incidental to good tillage and to spraying for the control of other pests has been referred to under the discussion of economic importance (p. 20-21). The regular spray applications for the control of the grapevine rootworm and the grape-berry moth are so timed that they are entirely effective against the larvæ of *Altica woodsi* but can not be relied upon to destroy all of the larvæ of *A. chalybea*. During both 1916 and 1917 the earliest larvæ of the latter species began entering the soil about 10 days before the first regular spray application was made. In case of a heavy infestation of larvæ of this species on the grape foliage an application made just before the grapes bloom is advisable to prevent a heavy infestation of beetles the following spring. This extra application, however, probably will be rarely necessary.

GENERAL SUMMARY.

The grapevine flea-beetle (*Altica chalybea* Ill.) is a grape pest which eats out the swelling buds in early spring, thus destroying the embryonic shoots and fruit clusters. Later both the beetles and the larvæ feed upon leaves of the grape. It is single brooded. Winter is passed in the adult stage. Eggs are deposited in groups under bud scales or strips of bark; the larvæ migrate to the leaves to feed and enter the soil to pupate; and the pupæ transform to the adult stage by early summer. This is in agreement with the habits and seasonal history as usually described in the literature of the species.

Statements that the eggs are deposited on leaves, that the insect is two-brooded, and that it prefers thin-leaved varieties of grapes as hosts rather than the Concord variety, are due to a confusion with a closely allied species, the lesser grapevine flea-beetle (*Altica woodsi* n. sp.), hitherto usually determined as "*A. chalybea*, small form." This insect is also single brooded but emerges from hibernation enough later in the season to appear as a second brood of the typical species. Eggs are deposited singly, or sometimes in a cluster of two or three on the underside of the leaf upon which they feed. As in the case of the first-named species, transformations are passed in the ground and winter is passed in the adult stage.

In addition to the above-mentioned characteristics, the lesser grapevine flea-beetle may be distinguished from its larger ally by its distinctly smaller size in all stages, by the green color of the adult instead of blue, the pale yellow of the egg instead of a deep yellow or orange, the yellow body color of the larva instead of a brownish yellow, and the absence of setæ on the ventral prothoracic plate of the larva. The feeding marks of both larva and adult are also a ready means of identification. Both the adult and the larva of the

lesser species merely pit the upper surface of thick-leaved varieties of grapes, and eat small holes in the foliage of thin-leaved varieties. Both stages of its larger ally strip the leaf tissue of varieties like the Delaware, while on leaves of varieties like the Concord the larva makes large whitish patches on the upper surface, and the adult, also feeding on the upper surface of the leaves, eats large holes in them.

Almost no other insect can cause as severe injury to the grape crop, in restricted areas, as that of which the grapevine flea-beetle is capable when the grape buds are swelling. The lesser species, which emerges later, is less destructive. Both species are sporadic in their occurrence from season to season and they are now restricted in their distribution largely to vineyards adjacent to wild grape arbors. A number of predatory enemies, of which *Lebia viridis* Say is the most important, contribute to its natural control.

Where vineyards are liable to injury from this pest, vigilance in early spring is essential to safety. When the beetles do appear their voracity makes prompt action necessary. If, as is usually the case, the infestation covers only a small area, hand-picking the beetles will probably be the most effective as well as the cheapest means of control, while if a large area is infested, spraying with arsenate of lead will probably be necessary. A spray application of 3 pounds of arsenate of lead paste (1½ pounds powdered) is ordinarily recommended, but if the infestation is severe and rains can be avoided, a dosage of not less than 6 pounds of arsenate of lead paste (or 3 pounds powdered) to 50 gallons of water may be used. The larvæ of the lesser species and most of those of the larger species may be readily destroyed by the usual spray applications for the grapeberry moth and the grapevine rootworm, and these measures, together with up-to-date vineyard tillage, make it practically impossible for these pests to reproduce in a vineyard and limit them to wild vines. Very rarely a spray application before the grapes bloom will be advisable to destroy the earliest larvæ of *A. chalybea*. These measures have probably been the cause for the change in the economic status of the grapevine flea-beetle from apparently a first-rate pest of 20 years ago to one of second-rate importance at present.

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L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

October 22, 1920

THE WESTERN CABBAGE FLEA-BEETLE.¹

By F. H. CHITTENDEN and H. O. MARSH,
Truck-Crop Insect Investigations.

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NATURE OF INJURY.

An insect enemy of cabbage, turnip, and other cruciferous crops, known as the western cabbage flea-beetle, ranks as a most troublesome pest in the region which it inhabits.²

It is primarily an enemy of gardens, but quite too frequently becomes a pest in large commercial plantings. The chief injury is done by the overwintered beetles attacking turnip, radish, and other cruciferous vegetables just as they are coming through the ground, and by the beetles of the first generation, which are usually at the maximum of their destructiveness during June and July. The beetles appear suddenly, and frequently in incalculable numbers, and large areas are completely devastated before the grower becomes aware of their presence.

Although the larvæ feed on the roots of cruciferous vegetables, they cause little appreciable damage.

The beetles are by no means confined in their injurious attacks to cabbage and other cole crops, since when they occur in unusual abundance they attack most forms of vegetable crops, including beans, peas, table and sugar beets, mustard, kale, and rape. As with

¹ *Phyllotreta pusilla* Horn; family Chrysomelidae, order Coleoptera.

² This insect was under observation by the junior author (deceased) from 1909 until 1917, at Rocky Ford, Colo.

the majority of flea-beetles, this species does most harm to young plants, and, as an instance of its destructiveness, it has been reported to come in swarms, like black clouds, completely covering the plants.

This species is not a periodical pest, like army worms and others, but it is more or less injurious year after year in the regions which it inhabits. It is, however, like most other flea-beetles, subject to considerable fluctuation in numbers for reasons which have not yet been entirely explained, but which are doubtless due to atmospheric conditions either at the time that the insect is breeding or when it is in hibernation.

DESCRIPTION.

BEETLE.

The adult of the western cabbage flea-beetle (fig. 1) is shining metallic copper in color, measuring one-sixteenth of an inch or a little more in length. The body is elongate oval, much flattened. The antennæ are slender and the same in both sexes. The thighs of the hind legs are strongly developed, fitting the insect for jumping, whence its common name of "flea" or flea-beetle.

Following is the original description of *Phyllotreta pusilla* (3,¹ p. 302):



FIG. 1.—The western cabbage flea-beetle (*Phyllotreta pusilla*): Adult, highly magnified.

Form narrow, elongate, depressed, piceous, surface with distinct æneous lustre. Antennæ slender, half as long as the body, piceous, joints 2-3 paler. Head scarcely visibly punctate. Thorax less than twice as wide as long, widest at middle, sides arcuate, apex slightly narrower than base, disc convex, surface shining, the punctures moderate, closely placed, but not convex. Elytra wider than the thorax, humeri obtuse, punctuation coarser than that of the thorax, closely placed, very little finer near the apex, but less dense, surface shining. Body beneath and legs piceous, abdomen sparsely punctate. Length .06—.08 inch; 1.5-2 mm.

Male.—Last ventral [segment] with a feeble triangular impression in the apex.

Female.—Last ventral simple.

The antennæ are alike in both sexes and the joints 3 to 10 vary little in length, although slightly broader externally.

This species is very easily confounded with related forms of similar habits. Prominent among these is *Phyllotreta albionica* Lec., which it resembles so nearly in form, size, and color that the females can scarcely be separated. It is, however, more shining, the head is nearly smooth, and the thorax and elytra are less densely punctate. Moreover, *Ph. albionica* may easily be separated by the male antennæ which have the fifth joint dilated. The female antennæ of the two species are almost identical. The color of *pusilla* is sometimes olive brown and inclined to black, but examination of a large series of properly preserved specimens does not show any material variation,

¹ Reference is made by number (italic) to "Literature cited," p. 21.

except in a few darker individuals from northern Colorado, the normal color being almost uniformly cupreous or copper-colored. The species is also apt to be confused with *Ph. acenicollis* Cr., but the latter may be readily distinguished, inasmuch as it is more convex, more shining, and distinctly larger.

EGG.

The egg is light yellow, glistening, of oval form, and about $1/50$ of an inch in length.

In confinement eggs were deposited in cracks in the soil about the roots of the cruciferous plants on which the larva subsists and there is good reason to believe that this is the usual habit under field conditions.

LARVA.

The larva (fig. 2, *a*, *b*) is thread-like in appearance, uniformly white, except for the head sclerites, the legs, and a chitinized area on the caudal abdominal segment, which are pale chestnut brown. The mature larva is about 5 mm. in length and from 0.5 to 0.65 mm. in width, or approximately 10 times as long as wide.

The larvæ feed normally on the roots of cruciferous plants and remain concealed in the soil throughout their life.

PUPA.

On reaching maturity the larva selects a suitable place for transformation and then wriggles about until it has formed a compact, well-defined cell in the soil, in the vicinity of the roots on which it fed. After the cell is formed the larva shortens and in about two days changes to pupa.

The pupa (fig. 2, *c*) is approximately of the same size as the adult and is entirely white. The arrangement of the antennæ, legs, and wings is the same as that of the average halticine pupa.³

DISTRIBUTION.

The range of the western cabbage flea-beetle, accorded by Horn and others, is from the Dakotas to Mexico and central and southern California.

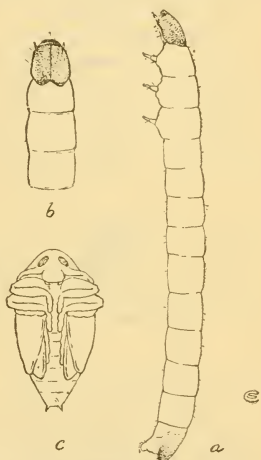


FIG. 2.—Western cabbage flea-beetle: *a*, Outline of larva, lateral view; *b*, head and thoracic segments of same, dorsal view; *c*, pupa. Enlarged.

³ Detailed descriptions of the immature stages are omitted from this paper because fresh material is not available and it is, moreover, desirable to compare all of these stages with those of related species and illustrate the same.

It is widely distributed in the Rocky Mountain region of Colorado and New Mexico, and is known to occur in more isolated localities in Arizona, Wyoming, Nebraska, Oklahoma, and Kansas. It is also abundant in some portions of Texas, ranging southward to Brownsville and undoubtedly into Mexico, although only doubtfully recorded from that country. The known distribution is shown in the map (fig. 3). This species is to be found quite frequently at very high elevations and is also evidently a permanent inhabitant of lower areas, as, for example, Brownsville, Tex. It is evidently a Sonoran form and common to both the Upper and Lower Sonoran Life Zones,⁴ but in some States it has been observed in the Semitropical, Transition, and Boreal Zones.

Undoubtedly the species has a wider distribution than is indicated by the map, comprising an area considerably larger in extent than one-third of the United States. It probably occurs in southern

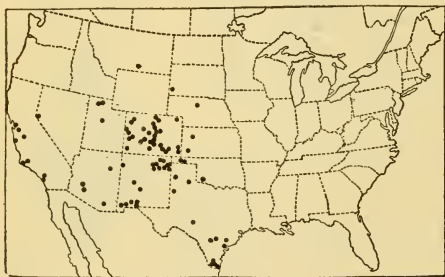


FIG. 3.—Map showing distribution of western cabbage flea-beetle.

Idaho, and without doubt is more widely distributed in the States of Nebraska, Wyoming, Montana, Utah, Arizona, and Texas than is at present known. While it does not approach the border lines of several other States known to be inhabited, nevertheless a

lookout should be kept in the future for invasions in southwestern Louisiana, southeastern Idaho, and Nevada.

REPORTS OF INJURY.

Our record of injury positively attributable to the western cabbage flea-beetle begins in 1889, the year when the species was described as new to science. That year, May 25, Prof. T. D. A. Cockerell sent specimens to the Department of Agriculture with the report that the insect did great damage to the leaves of turnip at Westcliffe, Colo. Injuries were reported at intervals in 1893, 1897, 1904, and 1906. In 1908 and 1909 there were several outbreaks over considerable territory, and a somewhat smaller outbreak occurred also over a large territory in 1913.

In 1893 Prof. R. Y. Croydon sent specimens from Laramie, Wyo., that were damaging turnips and radishes.

⁴ The species came under the observation of the junior writer at Rocky Ford, Manzanola, Fowler, Las Animas, Loma, Holly, Pueblo, Colorado Springs, Fort Collins, and Greeley, Colo.; Garden City, Kans.; Maxwell and French, N. Mex.; Sanibel and Mercedes, Tex.; Phoenix, Ariz.; and Thermal, Calif.

In 1897 specimens were received, July 10, from Mr. D. A. Pierce, Kennedy, Nebr., with the statement that the species had destroyed between 10 and 20 acres of corn in 24 hours. They were said to destroy everything in gardens. They came in swarms of black clouds and covered the plants. Later in the month Mr. Benj. F. Henry, Hill City, S. Dak., complained of a "flea"—a name commonly applied by farmers to flea-beetles—that was troublesome on cabbage and other cruciferous crops in his vicinity. Only a single grower in his neighborhood had saved any cabbage, all others having given up the fight against this flea-beetle. In addition to cabbage this species was injurious to radish, horse-radish, and turnip, and was, stated also to injure peas. On the last-mentioned plant it ate the lower leaves or lower part of the stalk. Out of 1,000 good cabbage plants our correspondent saved only a hundred. The beetles seemed to prefer the younger plants, but thrived also upon the older ones. A neighbor of our correspondent reported that he had not raised a turnip for seven years on account of this insect. It was prevalent in injurious abundance throughout the region of the Black Hills. The beetles were first noticed the last week of June, and seemed to disappear toward the end of July.

In 1904, during the first week of June, this species was observed by Prof. E. G. Titus, at Paonia, Fort Collins, and Longmont, Colo., and at Blackfoot, Idaho, June 22, attacking sugar beet. May 19, 25 acres of sugar beets were reported destroyed to date by this beetle at Grand Junction, Colo.

In 1906, Miss Hannah Carr, Mineral Hill, N. Mex., wrote January 11 of this insect destroying crops in that locality, particularly turnips, beans, and cabbage. From an acre of turnips only a few pounds of the vegetable were obtained. The same year complaints of injury to cabbage, radish, and nasturtium were received from Mr. Nathan Hall, Socorro, N. Mex.

The year 1908 witnessed severe outbreaks of this pest. April 24 Miss Margaret Botchleott, Grady, N. Mex., sent specimens with complaint of injury to garden plants. At Chico, N. Mex., it was injurious to cabbage. January 22, Mr. D. K. McMillan observed many beetles on turnip at Corpus Christi, Tex. The same year the species was received April 27, and later, from Mr. C. A. Pugh, Verne, Okla., where the beetle was reported to be injuring garden truck generally. June 4 Mrs. Frank Perron, Hurley, Tex., sent specimens with report that the beetles were entirely destroying radish and cabbage crops in the Coldun Tract in the panhandle of Texas. Mr. A. Olson, Blacktower, Roosevelt Co., N. Mex., October 25, writing of this species as the "garden flea" stated that it was generally found on radish, beet, lettuce, and in fact on almost all kinds of plants when they first come up. The insect perforates the small plants with holes and eats the substance until they die. The beetles were very

hard to catch and did great damage. The same year injuries were also reported to gardens in Verne, Okla., in April and May, and an invasion occurred at Brownsville and at Harlingen, Tex., on turnip and cabbage, in November. According to reports by Mr. McMillan, the beetles were to be found continuously through the month of November in south Texas.

In 1909 Mr. H. J. Kelley, Springton, Idaho, complained of this species, June 18. It was observed by Mr. M. M. High attacking potato at Lyford, Tex., March 2, and turnips and radish at Brownsville, Tex., March 26. July 25, of the same year, complaint by Mr. R. E. Chevick was made in regard to the same insect, on beans, cabbage, sugar beet, garden beet, and mangels. During July also, Mr. G. E. Thompson reported it at Akron, Colo., on kale and rape, and a heavy infestation at Fort Collins, stating that farmers complained of serious injury in their gardens, especially to cabbage, radish, and peas. November 7, H. M. Russell found the beetle at Compton, Calif., feeding on wild mustard.

In 1910 beetles were observed by Mr. High at Brownsville, Tex., in January, February, and March in large numbers on turnip, radish, and lettuce, doing great damage to young plants, the underside of the leaves being covered with excavations made by them. He wrote "in time this greatly devitalizes the growth of the plants and if the present number remains long enough, many of the leaves will wilt and die." March 2 the species was observed in numbers on young Irish potatoes at Lyford, Tex., by Mr. A. Steller.

During 1911, Mr. McMillan stated that in January and February this flea-beetle had been numerous at Brownsville, Tex., on wild water-cress (*Roripa sphaerocarpa*), wild pepper-grass (*Lepidium virginicum*), and on young turnip, mustard, and rutabaga. The beetles pass through partial hibernation, but their wild hosts were only slightly injured. July 2, this species was the subject of complaint at Goodwell, Okla., by Mr. Gus Shubert, who stated that in spite of different plantings the insect, locally known as the "earth flea," damaged radish, turnip, and cabbage. Serious infestation was reported the following day at Akron, Colo., to cabbage, lettuce, radish, and peas, and on July 25, to beans, cabbage, and sugar beets at Dulce, N. Mex.

June 10, 1912, injury was reported at Moses, N. Mex., to cabbage, radish, and turnip.

In 1913 this flea-beetle was observed in large numbers, January 27, at Brownsville, Tex., by Mr. High, attacking radish and turnip. The leaves were full of small holes made by the beetles. Injury was less noticeable on spinach and table beets. May 17, it was quite abundant on cabbage. Small excavations had been made on the underside of the leaves but were not yet entirely through the upper

covering. During the same year further injuries were reported to turnip, mustard, and radish at Amarillo, Tex.; to radish at Sheridan Lake, Colo., and to radish and turnip at Albert, Union Co., N. Mex. Of the last occurrence our correspondent wrote, "we can not raise these crops for the flea eats them as soon as they come through the soil." It was also injurious to cabbage, turnip, mustard, and radish at Tucumcari, N. Mex., and to radish at Thermal, Calif.

During 1914 Mr. F. B. Milliken reported this species attacking *Lepidium pubescens* at Garden City, Kans. He also observed larvæ from which the beetle was reared, May 17.

During 1915 this species was reported injurious to cabbage at Chico, N. Mex.; in 1916 to radish and cabbage at Fort Stanton, N. Mex.; and in 1917 to turnip, radish, and tomato at Golden, Colo.

During 1919 this species was apparently rare, having been reported in only four localities. At Brownsville, Tex., Mr. High found it attacking crucifers, and Mr. C. F. Stahl, Bureau of Entomology, collected specimens at Riverside, Calif., June 10 and July 14 on corn leaves. During July it made its appearance in injurious numbers at Lake Valley, N. Mex., where it was reported by Mr. John Avirette, attacking mustard, radish, and cabbage in the order named. He stated that without constant spraying with arsenicals these crops would all be ruined. August 26 of the same year Mr. A. E. Mallory, Bureau of Entomology, observed this species in moderate number on turnip.

July 16, 1920, Mr. D. J. Balagna, a grower and shipper of vegetables, Florence, Colo., wrote that this beetle was "destroying the entire valley," and unless something was done promptly, cabbage, cauliflower, and all related vegetables would be destroyed. Our correspondent had tried nicotine sulphate, coal oil and soap, arsenate of lead, salt water, lime, and Paris green, but found nothing that would kill it.

FOOD PLANTS.

The western cabbage flea-beetle, although normally an enemy of cruciferous plants, frequently does much injury to sugar beets and other vegetable crops. Turnip (*Brassica rapa*), mustard (*B. spp.*), and radish (*Raphanus spp.*) are decidedly the favorite food plants. The beetles also attack horse-radish (*Radicula armoracia*), rape (*Brassica napus*), cabbage (*Brassica oleracea*), cauliflower (*B. oleracea* var. *botrytis*), water cress (*Radicula nasturtium-aquaticum*, *Roripa nasturtium*), Chinese mustard or pe-tsai (*Brassica juncea*), nasturtium, bee-plant (*Cleome serrulata*), sweet alyssum (*Alyssum maritimum*), candytuft (*Iberis spp.*), wild peppergrass (*Lepidium pubescens*, *L. virginicum*, et al.), hedge mustard (*Sisymbrium spp.*), wild water cress (*Roripa sinuata* and *R. sphaerocarpa*), and tansy mustard (*Sophia pinnata*). All of these are normal food plants.

When the beetles occur in great abundance they injure also sugar beets and table beets (*Beta* spp.), mangel-wurzel (*B. vulgaris* var. *macrorrhiza*), lettuce (*Lactuca sativa*), beans (*Phaseolus* spp.), peas (*Pisum sativum*), carrots (*Daucus carota*), tomato (*Lycopersicum esculentum*), potato (*Solanum tuberosum*), and corn (*Zea* spp.).

Injury is due to the beetles eating pitlike holes in the leaves of young plants, usually selecting the lower surface. Radish is so seriously attacked practically everywhere within the destructive range of this pest that it is almost impossible in such regions to grow this vegetable unless strenuous efforts are made to prevent the inroads of the flea-beetle. Turnip and mustard are about equally attractive to the beetles and unprotected beds are frequently destroyed. Important injury to cabbage is confined to young plants in seedbeds or to plants soon after they have been transplanted in the field. Horse-radish is readily attacked and the foliage is often so completely riddled that it has the appearance of a sieve when held up to the light. This plant, however, is very resistant and the roots attain a good growth in spite of severe attack to the leafage.

The larvæ have been observed on radish, Cleome, and *Lepidium pubescarpum* only, but doubtless live on the roots of many other cruciferous and related capparidaceous plants. The injury done by the larvæ is negligible, so far as our observations go, in which respect this species differs from the related striped cabbage flea-beetle and horse-radish flea-beetle.⁵

SEASONAL HISTORY.

In its more northern range the beetle passes the winter months in hibernation under clods of earth, or under heaps of weeds, dead leaves, or other rubbish, whence it comes forth with the first warm days of spring. In the extreme South the beetles are active throughout the year but reproduction does not occur during the winter. In the Arkansas Valley the beetles issue from their winter quarters during the latter part of March or early April. At first the foliage of *Sophia pinnata* and horse-radish supply them with food. From these plants they go to early mustard and radish, and throughout the season or until severe freezes have occurred the beetles are to be found on various cruciferous vegetables and weeds. In south Texas beetles occur afield from February until December, being found, with the exception of two months, practically throughout the year.

There are apparently three generations annually in Otero County, Colo. Egg laying begins within a few days after the beetles leave their winter quarters—as early as April 14—and continues until early September.

⁵ *Phyllotreta vittata* Fab. and *Ph. armoraciae* Koch, respectively.

LIFE HISTORY AND HABITS.

OVIPOSITION.

Opportunity was afforded for observing the female of this flea-beetle in the act of laying her eggs, beginning June 18, 1915, at Rocky Ford, Colo. In a period of 12 minutes 17 eggs were deposited. When fully extruded, the ovipositor is from one-third to one-half the length of the abdomen. The total time taken in laying an egg varied from 2 to 5 seconds, 3 seconds being the average. During the laying there is a contracting movement of the abdomen, the ovipositor is extruded—not always to its full length—and an egg is forced through the opening. If, when the egg is forced out, it does not strike a surface and adhere to it the female twists the ovipositor about until the egg comes into contact with a surface to which it adheres. After an egg was laid the female generally ran about for a few seconds, then stopped and remained quiet for a few more seconds before laying another egg. Three different times the succeeding egg was laid at the same place within 3 or 4 seconds of the preceding one. As far as could be determined the eggs were not deposited in any particular order or arrangement, but were distributed quite promiscuously over the surface of the glass in the rearing cage. After having laid the last egg, the female ran down on the stem of a turnip leaf, which was in the cage, and commenced to eat. No further egg laying was observed, but as four other eggs were found it is presumed that they were laid before these observations began, which would give a total of about 21 eggs laid at this time.

Subsequently eggs were found in various other locations, one mass of 20 being laid on the soil, another of similar number on the lower surface of a turnip leaf, while others were scattered in small masses about the crowns of the plants.

The number of eggs that might be deposited by a single beetle was very difficult to ascertain and although attempts were made only two records of egg laying were obtained.

September 6, 1915, three beetles, two females and a male, developed in the cages at Rocky Ford, Colo. They lived through the winter under bits of earth in a rearing jar, and March 29, 1916, the male mated with one of the females. This pair was isolated in another cage and the record of the eggs deposited is given in Table I.

TABLE I.—Egg-laying record of a single female of *Phyllotreta pusilla*.

Date.	Number of eggs deposited.	Date.	Number of eggs deposited.
1916.		1916.	
April 3.....	21	May 21.....	19
12.....	27	25.....	32
21.....	23	29.....	27
29.....	23	June 6.....	21
May 6.....	16	13.....	20
9.....	15	Total.....	244

The female died June 20, and the male July 31.

The second female, which developed September 6, 1915, deposited 193 eggs beginning March 26 and ending July 26, 1916. She died July 30.

Females collected in the field and confined deposited from 27 to 163 eggs each, indicating that many of their eggs had been deposited before they were confined.

HABITS AND BEHAVIOR.

It was noticed in the occurrence of this insect in Otero County, Colo., that the beetles could best be collected during the middle of the day, the time when they were most active and were out on the plants in larger numbers. Earlier or later in the day they were usually found lower down on the plants around the crown or in cracks in the ground.

In order to collect them in numbers, a collecting bottle fixed somewhat as follows was used and found satisfactory: The bottoms of two small vials are broken out and then put end to end through the cork of the larger bottle (fig. 4). Upon inserting the neck of the outer vial over a beetle, it will invariably jump up into the vial. The neck is useful in that the beetle has a support to fall on if it does not secure a footing on the side of the vial. Hundreds of beetles can be collected in a bottle of this kind with small possibilities of any escaping. This form of bottle has been successfully used for the capture of other species of flea-beetles.

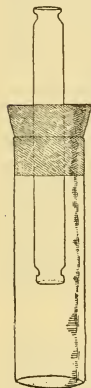


FIG. 4.—Device for collecting flea-beetles for study.

Adults mated from the middle of June to the middle of July, and were sufficiently abundant to do noticeable damage to small plants. Small radish plants were very much injured by the beetles eating into the stalk at the top or just below the surface of the ground, causing the plants to wilt and die.

In rearing experiments considerable care is required to see that the soil, or whatever the insects are in, does not become too wet or too dry. If the eggs are allowed to become too wet, they do not hatch; if not moist enough, they shrivel and dry up. In general, eggs require soil that is moderately moist.

The greatest difficulty in life-history studies was encountered in the larval stage. The larvæ were easily killed by excessive moisture, especially when accompanied by heat. Probably several thousand larvæ hatched but only a few lived to be adults. The most susceptible period is just after the larvæ have hatched. The laboratory temperature varied from 65° to 80° F. or above, with the maximum temperature for the larvæ about 70° F. This approxi-

mated more nearly the soil temperature in the field. Much below this the larvæ did not develop well and above 80° there was a considerable increase noticeable in the death rate. If too much moisture accumulates in rearing jars or "cages", the air becomes saturated during the day and at night cools off and condenses. This is detrimental to the larvæ, as they often become submerged in drops of water.

The young larvæ feed on the hair roots of their food plants and the older ones feed also on the main stalk and branches.

It was necessary to supply fresh roots every two or three days as decay is apt to set in. Parts of the crown of small turnips were supplied to the larvæ as food and they fed on this readily but did not seem to do as well as on fresh radish roots.

Upon reaching maturity the larvæ cease feeding and crawl restlessly around for a day or so before entering the soil. They make a distinct pupal cell with the inside compact and tightly cemented. Larvæ were observed in these cells, in a number of cases, for several days before they began to shorten. The contracted prepupal period ordinarily lasts 4 or 5 days.

Several times soil was secured in the field and brought to the laboratory and examined for larvæ or pupæ of this flea-beetle. In no instance was any larva or pupa observed. A number of examinations for larvæ and pupæ were made by digging around the roots of growing turnips and radishes, but neither was ever found in the field.

Since the eggs and larvæ in the laboratory seemed to be so susceptible to excessive moisture, the opinion was reached that it might be possible to control the species in the egg, larval, and pupal stages in the field by the practice of irrigation. Whenever the plants are irrigated, the soil around the roots is quite thoroughly soaked and it seems likely that the eggs, larvæ, and pupæ may not be able to withstand this.

LIFE CYCLE.

In working out the life history of the western cabbage flea-beetle adults were captured in the field and confined in cages consisting of battery jars and glass-covered boxes. The lid of a small tin salve box, filled with moistened earth, was placed in each cage, and in this earth the beetles deposited their eggs. The lids containing the earth were removed daily or at intervals of two or three days and placed in larger salve boxes. Food was supplied the larvæ by placing sprouted radish seed on the surface of the earth in the boxes. As the larvæ neared maturity most of the earth was removed from the lids in order to enable a close observation of the pupæ.

Owing to the extreme delicacy of the larvæ, it was impossible to rear large numbers at any one time. The small numbers of beetles which developed showed little disposition to breed and it was not possible to determine the number of generations occurring annually from any given "stock," or lot of specimens. The rearing records obtained, however, indicate the probability of three generations occurring annually in Otero County, Colo.

In Tables II, III, and IV records of the observed generations of the western cabbage flea-beetle in 1916 are given:

TABLE II.—*First generation of western cabbage flea-beetle.*

Item.	First generation.
Adults captured and confined.....	1916.
First eggs deposited.....	Apr. 10
First eggs hatched.....	14
First larvæ pupated.....	24
First adults developed.....	May 23
	June 3
	<i>Days.</i>
Egg stage.....	10
Larval stage.....	29
Pupal stage.....	11
Total duration.....	50

TABLE III.—*Second generation of the western cabbage flea-beetle.*

Item.	Second generation.
Beetles confined.....	1916.
First eggs deposited.....	June 24
First eggs hatched.....	26
First larvæ pupated.....	July 1
First adults developed.....	19
	25
	<i>Days.</i>
Egg stage.....	5
Larval stage.....	18
Pupal stage.....	6
Total duration.....	29

TABLE IV.—*Third generation of the western cabbage flea-beetle.*

Item.	Third generation.
Beetles confined.....	1916.
First eggs deposited.....	Aug. 8
First eggs hatched.....	12
First larvæ pupated.....	19
First adults developed.....	Sept. 10
	20
	<i>Days.</i>
Egg stage.....	7
Larval stage.....	22
Pupal stage.....	10
Total duration.....	39

HISTORY AND LITERATURE.

An account of this species, mentioned under the name of the Colorado cabbage flea-beetle (*Phyllotreta albionica* Lec.), was published by Riley in his 1884 report (1, p. 308),⁷ in which he stated that it was injurious to cabbage and other cruciferous plants in June and July throughout the Rocky Mountain region of Colorado, having been found in great numbers at the very highest elevations.

In 1889 Prof. T. D. A. Cockerell (2) mentioned this species under the same name, quoting from Riley's report. In a footnote, written by hand in a copy of his paper, appears "Dr. Horn says this is *pusilla* Horn and not the true *albionica* Lec." The same year Dr. Horn (3, p. 302) published the original description of the species.

In 1898 an editorial account of this species was given by Dr. L. O. Howard (4), citing injury at Kennedy, Nebr., and Hill City, S. Dak., previously considered in this bulletin under the heading "Reports of injury," p. 4.

In 1900 Messrs. Forbes and Hart (5, p. 471) published an account of this species under the title "The western cabbage flea-beetle, *Phyllotreta albionica* Lec.," stating that it was reported by Bruner as injuring sugar beets in Nebraska, and by Gillette as infesting cauliflower and other cruciferous plants and the bee-plant (*Cleome integrifolia*).

In 1903 the writer published a brief account of this species under its proper name, stating that it was observed doing considerable damage to sugar beet in portions of Colorado during 1901, preferring the younger plants (6, p. 18).⁸

In 1909 this species was recorded (8, p. 572) in brief as having been very destructive to radish, turnip, cabbage, and some other truck crops in Oklahoma, Texas, and New Mexico, in 1908.

NATURAL ENEMIES.

The western cabbage flea-beetle is singularly free from natural enemies. The three species, other than birds, which have come under observation are all internal parasites.

A BRACONID PARASITE.

Perilitus epitricis Viereck, a braconid ichneumon-fly parasite of the adult beetle, was found during practically all the three summer months. It was most abundant from the latter part of June to the latter part of July. Two adults emerged September 13, and one larva was found the same date. The larva probably emerges through the abdomen and under the elytra, although this point was not

⁷ Figures (italic) in parentheses refer to "Literature cited," p. 21.

⁸ Remarks made by Prof. R. A. Cooley (7, p. 260) that he believes this species to be the cause of complaints of injury to turnip and cabbage in the Yellowstone Valley, Mont., may refer to the related *Ph. albionica* Lec., although *Ph. pusilla* is known to occur in that part of the State.

proved. The larva spins a light gray cocoon in which it transforms to pupa, and the adult parasite emerges through a small hole which it eats out of the end of the cocoon. The greatest percentage of parasitized beetles observed at any one time was 16.

Just what influence this parasite has in holding the beetles in check has not been determined. It is sometimes an important enemy of the related striped cabbage flea-beetle (*Phyllotreta vittata* Fab.)

A NEMATODE PARASITE.

Nematodes infest the adult beetles. As generally observed these nematodes were young and small, about 1/40 of an inch in length. From 200 to 500 were counted in a single beetle. In several instances adult female nematodes were observed which had the body sack filled with newly developed nematode young that had not yet escaped.

As nearly as could be determined the nematodes were not confined to the digestive tract but appeared to be in the body cavity. In a number of cases eggs laid by the beetles were found to be infested externally with the nematodes. The eggs had an unhealthy appearance and in no instance were infested eggs observed to hatch. Just what effect the nematodes have on the beetles would be an interesting problem to work out.

A GREGARINE PARASITE (GREGARINA).

Gregarine worms⁹ occur in the intestines of the adult beetles, infestation averaging as high as 40 to 50 per cent, but it could not be determined whether these had any detrimental effect upon the host. They occur in almost all forms of insects and as far as known have no serious effect on them.

BIRD ENEMIES.

Mr. W. L. McAtee of the Biological Survey reports having found the western cabbage flea-beetle in the stomachs of three species of birds, and other beetles of the same genus in the stomachs of 12 kinds of birds. The land birds include among enemies of these beetles the common and Texas nighthawks (*Chordeiles virginianus* and *C. acutipennis texensis*), white-throated swift (*Aeronautes melanoleucus*), horned lark (*Otocoris alpestris*), starling (*Sturnus vulgaris*), song sparrow (*Melospiza melodia*), chipping sparrow (*Spizella passerina*), tree swallow (*Iridoprocne bicolor*), and marsh wren (*Telmatodytes palustris*).

CONTROL MEASURES.

EXPERIMENTS WITH INSECTICIDES AND DETERRENTS.

Ten experiments with arsenicals and one with nicotine sulphate were made in Otero County, Colo., by the junior author, and may be summarized as follows:

⁹ Identified by the junior author.

Experiment No. 1.—August 19, 1911.

Nicotine sulphate, paste.....	ounces..	3
Fish-oil soap.....	do....	8
Water.....	gallons..	10

It was noted that when the beetles were thoroughly wet with this spray they appeared to be soon killed. Later experiments, however, demonstrated that the beetles afterward came to life. Nevertheless, the single application showed considerable value, and if additional applications had been made to the same planting, the efficiency of this deterrent could have been demonstrated. Naturally no harm was done to the plants.

Experiment No. 2.—June 3, 1911.

Arsenate of lead was used with an equal amount of soap at the rate of about 6 pounds to 50 gallons of water, on radish, cabbage, and mustard, but as only one application was made the plants became reinfested.

Experiment No. 3.—June 22, 1911.

Arsenate of lead, paste.....	pounds..	6
Soap, common laundry.....	do....	6
Water.....	gallons..	50

In this experiment young cabbage was sprayed on both the upper and lower surfaces and the plants were heavily coated, almost white-washed, the spray adhering well. This had the effect of deterring most of the beetles and although no dead ones could be found it was evident that the spray acted as a powerful repellent.

Experiment No. 4.—July 22, 1911.

Arsenate of lead, paste.....	pound..	1
Whale-oil soap.....	do....	1
Water.....	gallons..	10

This was applied to radish and cabbage, the leaves of the latter being badly pitted. Every portion of the plants was wet on both the upper and lower surfaces. As in the previous experiments no dead beetles could be found and, although rainfall washed away much of the arsenate, in four days the plants had improved wonderfully and made excellent growth. As the rain left the plants practically unprotected a second spraying was made of the same mixture two days later. Nine days afterwards the cabbage was in excellent condition and practically free from insect pests, only an occasional beetle being found.

Experiment No. 5.—September 5, 1911.

Nicotine sulphate, paste.....	ounces..	4
Whale-oil soap.....	do....	8
Water.....	gallons..	10

After the application of this spray it was noted that the beetles which came in contact with the treated leaves jumped wildly and and after a brief struggle apparently died, but revived within half an hour. The plants showed no injury from the spraying.

Experiment No. 6.—April 29, 1912.

Arsenate of lead, paste.....	pound..	1
Whale-oil soap.....	do....	1
Nicotine sulphate.....	ounces..	5
Water.....	gallons..	10

This was applied to young mustard plants which were so small that only the upper side was treated. In this case the beetles were apparently dead but after being confined in a cage revived within an hour. The following day the plants showed an even coating of arsenate on the upper surface and were almost entirely free from the beetles. Some of the worse pitted leaves had died, became very dry, and crumbled when touched, but this was due to the attack of the beetles and not to the insecticides. This plat was examined at intervals, and a week later the plants were growing excellently. As the beetles began increasing in numbers an additional spraying was necessary.

Experiment No. 7.—April 29, 1912.

Arsenate of lead, paste.....	pound..	1
Whale-oil soap.....	do....	1
Water.....	gallons..	10

As in the previous experiment, the upper surface only was sprayed, radish and mustard being the plants treated. In this instance the infestation was so severe that many of the plants were so nearly destroyed that they failed to recover, partly because of hot, dry, and windy weather. It was only where the leaves were almost entirely consumed by the beetles that the plants died. The coating of arsenate was excellent and four days later the plants were growing well and were almost free from flea-beetles.

Experiment No. 8.—May 9, 1912.

The same formula as No. 7, applied to the same plants. Rain intervened for several days but nine days later the plants were described as growing beautifully and only moderately infested by flea-beetles, being beyond danger of injury. Although no dead beetles were found, the experiment was a success and the radishes were being sold at the time.

Experiment No. 9.—April 29, 1912.

A badly infested plat of mustard was dusted with dry Paris green inclosed in a cheesecloth sack, but there was a moderate wind and a considerable portion of the poison was blown away. The next day, however, although the plants were free from beetles they were nearly dead. Those which remained alive and were growing were practically free from flea-beetle attack.

Experiment No. 10.—May 2, 1912.

Arsenate of lead, paste.....	pound..	1
Whale-oil soap.....	do....	1
Water.....	gallons..	10



FIG. 1.—SPRAYING BEET FIELDS IN CALIFORNIA.

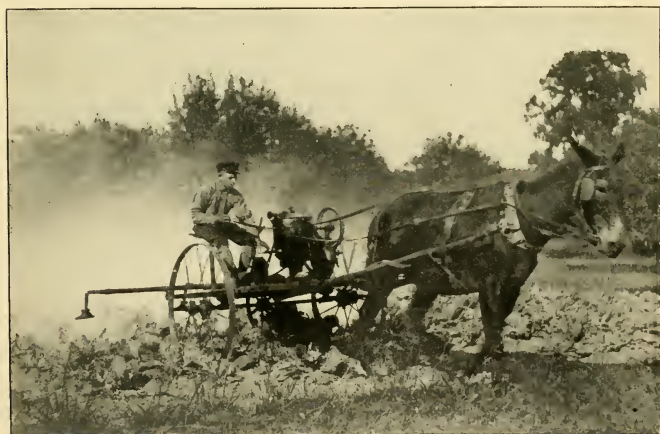


FIG. 2.—DUSTING CABBAGE WITH LEAD ARSENATE BY MEANS OF A TRACTION DUSTER.

THE WESTERN CABBAGE FLEA-BEETLE.

In this experiment radishes were sprayed and only the upper side was treated. A good quantity of the poison remained, no injury resulting from the spray, but no dead beetles could be found. Nine days later a rain fell, leaving many leaves unprotected, the beetles becoming abundant.

Experiment No. 11.—April 29, 1912.

A badly infested planting of mustard was dusted with undiluted arsenite of zinc. As in the foregoing experiment a moderate wind was blowing at the time and carried much of the poison away. The result, however, was practically the same, some of the poison remaining on the leaves, and although no dead beetles were found the plants were comparatively free from flea-beetle attack a week later.

It should be remarked that the plants at this time needed water but the irrigating ditch was dry.

RECOMMENDATIONS.

It appears to be practically impossible to kill an appreciable number of the western cabbage flea-beetles by spraying with arsenicals. Repeated experiments have shown that whatever application may be made does not kill the insects but drives them away. In other words, this insect can not be controlled by poisons, but by repellents and deterrents. The beetles are dainty in their feeding habits, carefully avoid foliage which has been sprayed, and attack either unsprayed portions or fly to other plants. Repellents such as tobacco dust are the most efficient of those which have been tested, and of the arsenicals, heavy applications of arsenate of lead have given the most satisfactory results.

LEAD ARSENATE.

In large plantings, and especially where cabbage is infested, spraying heavily with arsenate of lead is advised (Pl. I, fig. 1). The following formula has given excellent results:

Arsenate of lead, paste.....	pound..	1
Fish-oil soap (as a sticker).....	do....	1
Water.....	gallons..	10

This is at the rate of 5 pounds of lead arsenate to 50 gallons of water, or a trifle stronger than the standard formula of 4 to 50. One-half this weight of powdered lead arsenate, or 2 pounds in 50 gallons of water, is equally effective, with a corresponding quantity of soap to act as an adhesive or "sticker." It should be applied with a sprayer fitted with elbow extension, and a special effort should be made to coat thoroughly the under surface of the leaves. Two or three applications at 5 to 8 day intervals are sufficient even in case of severe infestation, provided the first application is made promptly on the first appearance of the insects.

BORDEAUX MIXTURE.

It has been known for many years that Bordeaux mixture is an almost perfect deterrent against flea-beetles. There is something extremely distasteful in it to this class of pests but unfortunately it has not been tested thoroughly either alone or in combination with arsenicals. It is recommended that tests be made both alone and in combination with arsenate of lead, arsenite of zinc, and calcium arsenate against this species. The standard Bordeaux formula 4-4-50 should be employed.

NICOTINE SULPHATE.

Experiments were made with nicotine sulphate at the rate of 3 ounces with whale-oil soap, 8 ounces, in 8 gallons of water, with the result that the beetles were stupefied although not killed. In these instances there is abundant proof that the flea-beetles were strongly repelled but further experiment is desirable to determine how often this preparation should be used, that is, at what intervals. Naturally since tobacco dust has been found successful, nicotine sulphate should be nearly as useful if not equally so.

INEFFECTIVE DETERRENTS.

In some regions where the western cabbage flea-beetle is destructive, growers dust the infested plants with air-slaked lime, ashes, insect powders, soot, or Paris green, but experiments made in Colorado have demonstrated that beneficial results from these substances, which also act as repellents, are of short duration in that State. The dry, high winds which prevail there render it difficult to apply an even coating of any form of dust or powder or to make such material adhere to the lower surface of the leaves where it is usually most needed.

A better coating, however, may be applied to the rough-leaved foliage of turnip, radish, and mustard than to the smooth-leaved cabbage, and some growers claim that the former class of crops may be efficiently protected by dusting with lime.

TOBACCO DUST.

A liberal application of finely ground tobacco dusted on the infested plants at 3 or 4 day intervals can be depended upon to protect radish, turnip, mustard, and similar vegetables from the beetles and for use on small areas is one of the most satisfactory control measures that can be recommended.

The accompanying illustration (Pl. I, fig. 2) shows a method of dusting with an arsenical or deterrent by means of a traction sprayer.

MAINTENANCE OF THRIFTY GROWTH.

In regions where the western cabbage flea-beetle is a dangerous pest the farmer is advised to keep the plants in vigorous condition

by frequent cultivation and heavy manuring in order to stimulate the growth of the plant and enable it to recuperate from insect attack. The irrigation system should be so installed that it may be kept constantly in working order, that the plants may not suffer at any time for lack of moisture. It should be unnecessary to add that the crops be kept free from other insects and from disease.

IRRIGATION.

Irrigation has been suggested as a remedy for the hop flea-beetle in its occurrence on sugar beets and should be of value where irrigation is practiced on other crops. Its effectiveness could be increased by brushing the plants, causing the beetles to jump into the water and be carried away or drowned.

MECHANICAL TRAPS.

The use of sticky shields and tarred boards, which have proved effective in the control of the hop flea-beetle in hop yards, might be used against this pest when it occurs in its greatest numbers. The conditions, naturally, are different, but there might be some cases where either would prove effective.

In 1914 Prof. H. M. Lefroy (9) made use of what he calls the Wisley turnip-fly trap against two allied species of flea-beetles¹⁰ in their occurrence on turnip with what he describes as amazing results, due apparently solely to the growth the seedlings make when their leaf surface is entirely unharmed. This trap is made of two boards set at a slope on a pair of runners like those of a sledge with a space between. The trap is drawn along the rows so that the plants pass through the space in the middle. In order to disturb the beetles a loop hangs from a crossbar and brushes the plants. The boards are smeared with a sticky substance, which captures the beetles as they fly up. The illustrations furnished of the trap show that it can be easily made and should prove quite successful where radish, turnip, and similar crops are planted in rows, but, of course, would not be of service where the seed is sown broadcast.

TRAP CROPS.

The fondness of this, as well as other cabbage flea-beetles, for radish, mustard, and turnip suggests the employment of these as early trap crops to attract the beetles from the later-appearing main crops of cabbage, sugar beet, and others. The beetles may be swept up from these trap crops by means of a bag sweep net of the type used by entomologists to collect beetles and similar insects. This should afford protection for the main crop.

¹⁰ *Phyllotreta consobrina* Curt., and *Ph. undulata* Kutsch.

CLEAN CULTURE.

The habitual appearance of this species in great abundance on young plants is a factor which prohibits the use of anything except immediate application of poisonous substances like the arsenicals or repellents, but there is little doubt that in the course of time this pest will lessen in numbers, provided concerted action is taken to control it. Among the best remedies to be employed is the establishment of clean culture throughout the year from early spring until the crop is off and even thereafter. To accomplish this all cruciferous and related weeds on which the insects normally feed and breed should be kept down. It is desirable, therefore that the grower become familiar with all of these plants, or else it will be necessary to destroy all weeds and keep the fields free from them at all times. This may be accomplished by the ordinary process of weeding and by burning over after the crop is off and again before the crop is planted. Plowing over may be sufficient at either time.

SUMMARY.

Cabbage, turnips and other cole crops, sugar beets, other vegetables, and garden plants, are severely injured in the Western States by a minute flea-like beetle known as the western cabbage flea-beetle. Injury is chiefly due to the overwintered beetles during June and July, but the beetles accomplish more or less injury during the growing season. This flea-beetle develops on the roots of wild and cultivated cruciferous plants. The beetles frequently appear in great numbers, eat minute pitlike holes in the leaves of young plants, and often cause considerable injury in seed beds.

The entire life cycle from egg to adult may be passed in about 30 days in June and July and there are at least three generations produced annually.

Crops may be protected by means of a spray of arsenate of lead, applied at the rate of 2 pounds, powder, to 50 gallons of water, or by Bordeaux mixture, 4-4-50 formula, these sprays acting as repellents. It can also be controlled by nicotine sulphate, $\frac{1}{2}$ pint 40 per cent solution in 50 gallons of water with 2 pounds of soap added, and by tobacco dust, which are deterrents. It is not possible, however, to control this insect entirely when it occurs in its greatest abundance.

In addition, it is desirable to keep the plants thrifty and well watered; mechanical and trap crops can be used with advantage, and clean culture is always advisable, especially the destruction of weeds in and near cultivated fields.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.

PROFESSIONAL PAPER

April 22, 1921

THE
GRAPE PHYLLOXERA IN CALIFORNIA

By

W. M. DAVIDSON, Scientific Assistant, and
R. L. NOUGARET, Entomological Assistant,
Deciduous Fruit Insect Investigations

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CALIFORNIA HISTORY.

EARLY VINE PLANTING IN CALIFORNIA.

The grape phylloxera is not native to California. It has long been recognized as originating in North America, but its native habitat is east of the Rocky Mountains. The insect has not established itself upon the native vine of California (*Vitis californica*) in the wild state, whereas in Arizona it is established on native vines.

¹ *Phylloxera vitifoliae* (Fitch).

² Now in charge, Viticulture Service, California Department of Agriculture, Sacramento, Calif.

NOTE.—In connection with other work in California, the office of Deciduous Fruit Insect Investigations, Bureau of Entomology, in cooperation with the Bureau of Plant Industry, has been engaged in an investigation of the grape phylloxera during several years past, with principal headquarters for the work at Walnut Creek. The work inaugurated by E. L. Jenne, upon his death was taken over by S. W. Foster, assisted by R. L. Nougaret. Upon Mr. Foster's leaving the service, the investigation was continued by Messrs. Nougaret and Davidson, the latter giving especial attention to biological and life-history studies and the former to investigations in the field and to remedial operations. The present report deals with the history, injuries, and life history of the insect in California. Remedial measures will be made the subject of another publication. It has been necessary to omit an extended bibliography of the subject.—A. L. QUAINANCE, *Entomologist in Charge of Deciduous Fruit Insect Investigations.*

More specifically, the insect is a native of the Mississippi Valley, where the vines have developed a resistance to phylloxera, and such species as *Vitis riparia*, *V. rupestris*, *V. aestivalis*, etc., thrive, notwithstanding the presence of the insect. These wild species possess varying degrees of immunity and through scientific selection and hybridization have yielded types of vines possessing inherent degrees of immunity, known to viticulture as resistant vines, or resistant stocks when designated as a root upon which to graft commercial varieties of grapes in order to circumvent the ravages of phylloxera.

Vitis californica is a wild species of vine found not only in California but throughout the Pacific coast. Because normally found free of phylloxera in its wild state, it was at one time tried out as a resistant stock upon which to graft commercial varieties, but proved a complete failure in all but one or two instances. Even under normal conditions and environment, when once attacked it succumbs to the injury by the insect.³

The Mission grape is a cultivated variety of *Vitis vinifera*, and although of European origin, its introduction to the Pacific coast is so intimately related with the first settlement of California under Spanish rule that it well deserves the oft-attributed title of "California grape" (7)⁴. The Mission grape was introduced into California by the Padres of the Roman Catholic missions. As early as 1524 (18, p. 17), while Cortez was governor of Mexico, then called New Spain, seeds and plants were most often part of the cargo of vessels plying between the mother country and her colonies. Grapes and olives are plants mentioned as being among these. It is to be assumed that about that time *Vitis vinifera* varieties were introduced into Mexico from Spain⁵ through both cuttings and seeds (1, v. 2, p. 131-133; v. 3, p. 613).

³ In the Annual Report of the California Board of State Viticultural Commissioners for 1887, published in 1888, pages 47-48, may be found the following: "While visiting Mr. Hagan's vineyard, we were led to examine an old vine—*V. californica*—which appeared like one infested with phylloxera. This surmise proved correct * * *."

"The commission has often sought for evidences of phylloxera on our wild vines in their native state, but up to this time none has been found, this being the first case of the kind discovered." (See "Literature cited (5)," p. 127.)

⁴ Numbers in parentheses refer to "Literature cited," p. 127.

⁵ In this connection F. T. Bioletti, professor of viticulture at the University of California, writes as follows: "No one has yet been able to trace the Mission grape with certainty to any European variety. It is a remarkable coincidence, if nothing else, that a Sardinian grape known as the Monica resembles the Mission very closely. The Monica is said to be a favorite grape of the monks in Sardinia, and it seems probable that the missionary monks of Mexico, finding it difficult to transport cuttings from their original homes, obtained seeds of the grape which they liked the best and that from the seedlings grown they chose the one which most resembled the grape they were looking for. If this is in accordance with the facts, the Mission is simply a seedling of the Monica."

He further advances the suggestion that the Mission might be a seedling of the Monica, as published in a report (2) of the viticultural work of the agricultural experiment station of the University of California * * * 1887-1893.

Later, in the early part of the eighteenth century, a long line of missions was established throughout the peninsula of Lower California, the Mission of Loreto being the first, in 1697. These missions all grew grapes. The vines were furnished to them originally by the colonies of Mexico. As missions were founded, products and plants were furnished to the new one by the older established ones, and grapes are almost always mentioned as being cultivated by the Padres.

The Mission of San Diego was the first to be founded in upper California, and the vines planted there were brought from the missions of Lower California. As no other variety but the Mission grape is known to have been cultivated by the different missions which were founded in after years, it is to be presumed that it was introduced into this State with the founding of the Mission of San Diego, 1769.

The Mission is a long-lived, vigorous, and thrifty vine, as is attested by two remarkable specimens. The one planted in 1775, and still living, is on the property of the San Gabriel Mission in Los Angeles County, is trained on an arbor, covers 9,000 square feet, and its trunk just below the surface of the soil has a circumference of 9 feet. The other, planted in 1842 near Carpenteria, died in 1915, presumably of the "Anaheim disease." It measured at its base $8\frac{1}{2}$ feet in circumference; at a height of $6\frac{1}{2}$ feet it divided into three branches, one of which measured $3\frac{1}{2}$ feet in circumference. As an arbor it covered one-fourth acre, and in 1895 yielded its maximum crop of 10 tons, its average crop being estimated at 5 tons.⁶

The Mission grape in early days was planted by the Padres around the missions and was used both as a table grape and especially for making wine. Gen. Vallejo (7) is authority for the statement that the Mission grapes grown at the Sonoma Mission were of a better quality than those grown at the other missions in California, and that a recognized superior quality of wine was made from them.

It was probably because of this reputation that the first commercial vineyards of wine grapes were established in the vicinity of the town of Sonoma. In this district the grape phylloxera was first discovered, and the dying of the vines, which for some time had puzzled the viticulturists, was finally determined to be the result of this insect's attack. An importation of vines from Europe of unparalleled importance up to that time for California, and one which may adequately be termed a "pioneer importation," occurred at about this time and very shortly prior to the discovery in France of the phylloxera, thereby furnishing grounds for the subsequent report, more or less widely spread throughout the State and which persists

⁶ Details of its history can be obtained from the secretary of the Carpenteria Chamber of Commerce.

even at this late date, though refuted at different times by investigators, that this importation of European vines was responsible for the introduction of phylloxera into California. This is a mistaken idea. The history of the grape industry virtually proves that the insect was imported with American species or varieties of grapes from east of the Rocky Mountains.

FIRST DISCOVERY OF GRAPE PHYLLOXERA IN CALIFORNIA.

The first evidence of phylloxera infestation in California dates as far back as 1858. The dissemination of phylloxera continued for years in California before the existence of the pest was known, although its destructive work was observed, commented on, and designated a disease of vines from unknown causes. Reference to the first discovery and determination of the insect in California is to be found in a report (4, p. 108-111) dated August 28, 1880, and submitted by H. Appleton. In his report the first ravages witnessed in California are discussed, and from them is inferred the date of introduction of the insect. Extracts from this report follow:

On the nineteenth of August, 1873, an insect was found on the roots of grapevines by H. Appleton and O. W. Craig, in the vineyard of the latter, situated two miles north from Sonoma Town, on the west side of Sonoma Creek. An investigation was ordered at the time, for though the insect was identified as "the insect, or louse, known in Europe by the title of *phylloxera-vastatrix*, and in the United States as *pemphigus vitifoliae*," there existed a doubt in the minds of the investigators, because the injury was confined wholly to the roots of the vine, and no symptoms of injury such as recorded in Europe and in Eastern North America could be detected on the leaves.

From information received from Mr. A. F. Haraszthy and Captain E. Cutter, Superintendent of the Buena Vista Company's vineyards, I am able to give the following facts in regard to their large vineyards:

A vineyard of about one thousand vines was planted in 1834-35, and was watered every year. In 1850 and 1852 the vineyard was largely increased, and the system of irrigation was stopped. In 1857 about two hundred thousand vines were set out, and in 1858 one hundred acres were put in vines (six hundred and eighty vines to the acre). Again, in 1860, fifty acres were laid out. In 1862, Colonel A. Haraszthy planted 70,000 European vines, and it was among these vines the disease increased most rapidly.

In the Spring of 1863 the Buena Vista Company was incorporated, and in the Spring of 1864 that company planted 100,000 vines.

As early as 1860 decayed and dying vines were noticed in the vineyard, and they were taken up and others planted in their places. An examination was made to discover the cause of the disease in these vines, and it was attributed to alkali water, which was found a few feet underground. The roots were decayed. No examination by microscope of these roots was made. Vines died from time to time, showing short growth, small and colorless grapes, early yellow leaves—in fact, all the symptoms were observed of vines dying from the vine pest.

In 1868 about 3 acres of diseased vines were taken up (planted in 1850) on the north side of the dwelling house, and new vines planted, which grew well, showing little signs of decay till they were four years old, at which time (1873) the Phylloxera Committee, of the Viticultural Club, found the phylloxera on several vines.

The facts of this statement are significant and by no means ambiguous if considered in the light of the knowledge possessed to-day of the life history and habits of phylloxera, the nature of its injury, and the progress of its ravages.

This report also indicates how and when the first impulse was given to the development of the grape and wine industries of the State, then in their infancy. As interest grew in this direction, better varieties of grapes than the Mission would naturally be sought and given a trial. This was the case with the eastern variety of grape, the Catawba, a vine susceptible to the attack of phylloxera because of its fleshy roots and successfully grown at that time in the East as a wine grape. A weekly agricultural paper, the California Farmer (6), under date of Thursday, January 23, 1855, in an editorial article entitled "The Catawba Grape," says:

We sincerely esteem the Catawba grape, one of the very best varieties for cultivation in California. Longworth of Ohio, whose famous Catawba Champagne is now esteemed equal to any wine imported, says it is the very finest wine grape known. Will be found far superior to our California Grape [Mission]. We earnestly urge our cultivators to give the Catawba a careful trial.

The same agricultural periodical from time to time that same year published other articles⁷ eulogizing not only the Catawba but also other vines of eastern varieties and quoting fabulous yields in wine and profits.

Articles such as these undoubtedly influenced the planting of eastern varieties, if only as an experiment. Can it be doubted that many vines were brought from the East to California and the phylloxera introduced with them?

The variety of grape planted in 1850-1852 in the Buena Vista vineyard is not mentioned. It is more than likely that the major part of the planting was of Mission. If these vines were inoculated with phylloxera shortly afterwards by means of a few eastern grapevines planted near by, the vineyard would have experienced a spread of invasion as related above by Appleton. Evidence of the insects' injury would be apparent as affecting only a few vines during a few years or up to about 1860, and eight years later the vines, covering an area of 3 acres, would have become so dwarfed and nonproductive, with perhaps a few dead, that it would be necessary to grub them up. That this vineyard trouble was due to phylloxera is emphasized by the further statement that the 3 acres were again replanted with new vines, and during the four following years (1869-1872) the vines were again affected in a similar manner, but to a slighter degree, just as a recurrence of infestation would act if vines were planted in infested soil. Finally, in 1873, just five years

⁷ E. g., "What are the best grapes;" "Extracts of the Cincinnati Gazette."

after the replanting of the 3 acres, the committee of the Viticultural Club discovered the phylloxera on the roots of several of the replants.

The history of this vineyard proves conclusively by direct and circumstantial evidence that the trouble was due to phylloxera. It localizes the infestation, describes the progress and spread of the injury, and, by fixing dates, determines the period of time the progress covered. Finally, the presence of the insect is discovered and its identity determined.

In 1861 Gov. Downey, of California, appointed three commissioners to work in the interests of the grape industry, two of the members of this commission being Don Juan Warner and A. Haraszthy. The latter was sent to Europe to purchase for the State for distribution different varieties of grapes, and the result was the importation of 200,000 cuttings and rooted vines, comprising 1,400 different varieties of grapes from all the vine-growing countries of Europe and also from Asia Minor. It may be that some of these imported rooted vines harbored phylloxera, which already had caused considerable damage to vines in France, although the insect was only discovered in that country the following year (1862). It is quite likely that a good portion of the 70,000 vines planted out on the Buena Vista vineyard in 1862 and referred to in Appleton's report were propagated from this importation and that the pest may have been introduced simultaneously with the planting of the vines. The rapid destruction of the vineyard, as stated, however, could have been brought about in the case of the young vines just as well by infestation communicated by the old vineyard.

The history of the Orleans Hill vineyard furnishes an insight into the methods of establishing vineyards with varieties of grapes imported from Europe in the early days of grape culture in California, and helps to give grounds for the belief that the earliest and original introduction of phylloxera into this State was due to eastern varieties of grapes only.

Data of this history are contained in a report, dated 1880, submitted by the owner of the vineyard (4, p. 112). In 1853 the owner imported from Nassau, on the Rhine, in Germany, 15 varieties of grape cuttings (*vinifera*) and planted them in his garden near Sutters Fort, Sacramento, where they flourished splendidly and showed no signs of disease. In 1859-60 many vines were propagated here for planting the Orleans Hill vineyard in Cache Creek Canyon, Solano County. This vineyard was set out in two different situations, part being on a hillside and part in a flat. In the latter situation the soil was of a stiff clayey nature and the vines did not do as well as on the more friable hillside soil, and this necessitated replanting, for which there were procured later from Napa some Zinfandel vines.

The date when these replants were procured is not specified, but was probably about 1864 or 1865. Before the date of replanting the phylloxera had infested the Sonoma Creek district and had spread to Napa County.

In 1859 a horticultural exhibit was held in the agricultural hall just completed that year at Sacramento, and the records of the State Agricultural Society mention exceptionally good exhibits of grapes by progressive fruit growers. The eastern grape Catawba is twice mentioned.

From another report (4, p. 29-30) we learn to what extent the eastern varieties of grapes were grown prior to 1875 in El Dorado County. No mention is made of earlier dates, but it is more than probable that the European grapes were already supplanting the eastern ones, judging by the few of the latter type which were planted in later years and which to-day are found only in family vineyards and gardens. This report, written by Mr. G. G. Blanchard, commissioner of the State board of viticulture, further stated that what was true of El Dorado County could also be said of Nevada, Placer, Amador, Calaveras, Tuolumne, and Mariposa Counties. A passage reads:

The proportions and kinds (grapes) growing, taking one hundred as the sum, are as follows: Mission, or native grapes, sixty-eight; Catawba and Isabella, ten; White Muscat, Muscatella, Malaga, six; Tokay, Black Morocco, Malvoisies, one; Zinfandel, Riesling, two. The other thirteen are made up of numerous other varieties, such as Sweet Water, Black July, Hartford Prolific, Cloanthe, and Concord, and some others.

In this enumeration eastern grapes would represent approximately 23 per cent of the varieties grown. We thus see the important part played by eastern varieties of grapes in the earliest plantings and can conceive how the pest was introduced directly from its natural habitat.

ACCIDENTAL AND NATURAL SPREAD.

Centers of infestation, when compared according to the modes of dissemination which they engender, are of two kinds: Accidental and natural. An accidental distribution center would be a nursery which imported, unwittingly, phylloxera-infested grapes, propagated the vines, and by so doing bred the insect and disseminated it with the sale and shipment of these vines. The same is true when vines are procured from phylloxera-infested districts. For new plantings or replants, such a center would be the infested locality in Napa, from which the Zinfandel vines were the means of introducing the pest into a locality as yet free from it. In turn, the Orleans Hill vineyard became a natural distributing center because the insect by its natural increase and habit spread to other parts of the same vineyard or even to other vineyards of the district.

Infestation from accidental distributing centers may be avoided by strictly enforced quarantine measures.

Accidental spread has been the main cause of most of the phylloxera infestation throughout the vineyards of California because of its being an initial inoculation, developing later into a center of natural dissemination.

A general survey of the growth of the grape industry, which at times, as in the late eighties and early nineties, attained the proportion of a boom, furnishes an indication of the accidental spread which took place concurrently.

Cuttings were used almost exclusively for planting vineyards in preference to rooted vines, the latter being used for replanting "misses," and even then not commonly used. As will be shown later, there is little, if any, danger in disseminating the phylloxera from cuttings, unless these are heeled in in infested soil while awaiting shipment. It is for this reason that the accidental diffusion was greatly restricted. If rooted vines had been commonly used, originating from the same district as the cuttings, the accidental diffusion would have been so general as perhaps to have precluded before long the growing of vinifera vines on their own roots.

THE WINGED MIGRANT NOT A FACTOR IN SPREAD UNDER CALIFORNIA CONDITIONS.

Profiting by the investigations and experiments that were being carried on in France, the University of California in conjunction with the State Board of Viticulture made extensive efforts to arrest the ravages of the phylloxera, and made investigations pertaining to its life history and habits. These deserve special mention in this report.

Dr. F. W. Morse (16) of Oakland, Calif., during the period 1881-1886, as an assistant in the General Agricultural Laboratory, discovered in the course of his investigations on August 26, 1884, specimens of the gall louse or leaf-inhabiting form of the phylloxera. As is noted under the heading "The gallicole and its relation to California conditions" (p. 95), this is the only recorded instance of the finding in California of the leaf galls. In this connection it may be said that in the experimental vineyards of the Bureau of Plant Industry, United States Department of Agriculture, in which are collected many varieties and hybrids of species of American vines, not a few of which are susceptible to leaf galls when cultivated in the Eastern or Middle States, an exceptionally good field for observation is offered. Mr. G. C. Husmann, under whose direction these vineyards are conducted, states that the leaf gall, to his knowledge, has never been found in them. Extensive correspondence

with entomologists and prominent viticulturists in California elicited the same information.

Laboratory experiments, conducted under favorable conditions to obtain winter eggs with the existing strain of phylloxera in California, have failed to go beyond the production of the winged form in specially devised cages, although in other laboratory experiments the sexed forms were produced and the discovery in the natural state of a single winter egg must be mentioned.

A study of the life history has corroborated the observations of Dr. Morse relating to the sterility of a portion of the winged migrants and to the sterility of some and the debility of the remainder of their progeny. The writers' observations demonstrate that the normal life cycle of the insect in California is wholly parthenogenetic and that the natural spread, or diffusion, is due entirely to young radicle larvae possessing migratory instincts, at least during July, August, and September, and to which has been given the name of "wanderers" to distinguish them from "migrants," a term which commonly is applied to winged forms of the Aphididae.

The conclusions of the investigations of Dr. Morse point to the possibility of such a condition, though not affirming that the winged migrant is not responsible for the diffusion of the species in California. The late Prof. E. W. Hilgard (14) shared this view, which he expounded in his report, in which he indicates the discovery by him of one of the first phylloxera spots in Napa Valley, as follows:

The first phylloxerated "spot" within the Napa Valley was observed by me in 1877, close to the stage road and public highway leading directly from the worst-infested portion of Sonoma, and on which vineyard material was, and is, constantly being hauled back and forth. It is plainly from this highway and its infested wagonloads that the insect has spread in the Napa Valley.

The "spot" alluded to is believed by the writers to have been either in the old Squibb vineyard (10 acres), in the old McClure vineyard adjoining, or in the Callan vineyard (50 acres). All these were located close together. They have long since been pulled up, the land is now pasture, and only a very few of the old original vines still exist, although browsed down by the stock. These vines date back to 1866.

From present knowledge of the biology of the phylloxera, it is believed by the writers that the vineyard material referred to by Prof. Hilgard was responsible for the spread of the pest to this location, but the inoculation was due to the wandering young radicle larvae rather than to the winged form.

PHYLLOXERA SPREAD BY PICKING BOXES.

"Vineyard material" may imply many sources of infestation. Besides rooted vines, grape-picking boxes are very likely to trans-

port the insect from one district to another. At times grapes are delivered to the wineries in greater quantities than can be handled, and boxes of grapes are unloaded and left at the winery instead of their contents being emptied into the elevators and the empty boxes returned to the same wagon. Boxes are exchanged, and some from infested districts find their way to uninfested vineyards. Wandering larvæ (wanderers) easily shelter themselves in cracks and joints of boxes while these remain strewn throughout the vineyard waiting to be filled with grapes, and when the boxes are transferred to other vineyards, after having been emptied at the winery, the insects may be released by the shock of the empty box against the ground in the process of unloading.

In their practical experience, certain grape growers have noticed that the first signs of phylloxera in their vineyards appear at places where they have been in the habit of dumping boxes for the convenience of grape pickers.

There were a number of wineries, reputed for the excellence of their wines, in the early-infested district around Glen Ellen, Sonoma, and Los Guillicos, and grapes were hauled to them from afar at about the time vines were dying rapidly in their vicinity. This accounts, no doubt, for the several early centers of infestation which appeared in a short period of time in Napa County.

The pest spread into Napa County from Sonoma County not only along the highway to and beyond the vineyards cited in Prof. Hilgard's report, but also over the ranges of hills referred to in the same report by means of a mountain road which ran over the divide from Sonoma and descended into a long narrow valley (Brown Valley), which itself opened out into Napa Valley quite close to the city of Napa. At the head of Brown Valley and almost on the county boundary line is the Dell vineyard. From the owner, Mr. C. Dell, the following information was obtained: In 1867, 20 acres of Mission grapes were planted with cuttings obtained from the Wing vineyard (then owned by Buhman Bros.), material for which formerly had been secured from the Buena Vista district at Sonoma. After seven years the Dell vineyard began to show signs of phylloxera in small patches, but bore good crops for four years. The Wing vineyard, located close by, began to die at the same time.

The phylloxera was introduced in this case probably by means of picking boxes, or else by rooted vines planted to fill out places where the cuttings had failed. If the dates are correct, the infestation would have been noticed, without the cause being known, in 1874, or about the time it was discovered along the Sonoma highway.

The above data are recorded to indicate how important a rôle this Sonoma Creek district played in the first introduction of the insect into California and how the spread occurred through different chan-

nels. For this reason the early plantings give an idea of how the insect could have been spread before its presence was suspected.

PRACTICAL METHODS EMPLOYED TO ARREST THE SPREAD OF THE PEST.

When the discovery of phylloxera in California was first made known, the grape growers were already acquainted more or less with the havoc it had produced in the vineyards of France, and a panic spread throughout the different grape districts. It soon subsided, however, when the vineyards were not being rapidly destroyed, and even precautionary measures were overlooked.

Of all the grape-growing counties, that portion of Alameda County known as the Livermore Valley district evolved the best organized system of quarantine measures, the aim of which was not to prohibit the importation of vines into the county, but to have cuttings, as well as rooted vines, thoroughly disinfected before they were permitted to be planted.⁸

The disinfectant used was a commercial soluble phenol. Vines were immersed for one-half hour in a solution of 1 part phenol to 60 parts water. Notwithstanding these precautions, vines were introduced without the knowledge of the quarantine commission, and there occurred three distinct centers of infestation from which the pest was remarked to spread with the prevailing summer winds. Two of these centers were planted originally with material from San Jose, and the third with vines from St. Helena, in Napa County.

DISTRIBUTION OF PHYLLOXERA IN CALIFORNIA.

As far as has been observed, Stanislaus, Merced, Kings, and Madera Counties, north of Tehachapi Pass, are free from phylloxera. South of Tehachapi Pass it has not been found so far. Most of the counties named have either enacted ordinances establishing prohibitive quarantine against the importation of grapevines or protective measures subjecting vines to strict inspection and fumigation.

The absence of infestation is without doubt not wholly due to quarantine measures, which were enacted years after the pest had many opportunities to be introduced, but more likely is due to the combined conditions of climate and soil in these counties.

The writers have made a personal investigation of the present status of phylloxera infestation, and have tried to ascertain and estimate approximately the damage caused to the viticultural interests. At this late date, however, there is much difficulty in obtaining information on which to base the estimate. Quite a number of vineyards have been replanted, some as many as three times; property has changed hands, and the history of vineyards has been forgotten. Again,

⁸ Data personally contributed by Charles A. Wetmore, formerly chief executive of the State board of viticultural commissioners.

[illegible]

the State Board of Viticultural Commissioners and other agricultural and horticultural reports is presented. This, with the aid of a map of California (fig. 1) to indicate infested counties in shad-

ings to correspond to a period of years within certain dates, will enable one at a glance to conceive the degree of injury produced and the loss sustained by the viticultural interests.

A general idea can be formed of the growth of the viticultural interests of California and correlatively of the economic importance of the grape phylloxera by comparing the report on grape production of the State statistician for the year 1914 with the report of a similar nature for the period 1856-1866 (Table I).

TABLE I.—*Planting of vines in California in different periods.*

County.	Vines planted in—			Total vines existing in 1865.	Total bearing vines existing in 1866.	Total vines existing in 1910.
	1856	1857	1858			
Alameda.....	48,000	125,000	175,000	1,575,000	155,070	2,390,959
Amador.....	9,000	8,000	20,000	180,000	757,773	314,604
Butte.....	15,000	45,773	80,707	726,363	369,785	258,742
Calaveras.....		6,465	24,187	217,665	515,049	212,300
Colusa.....	10,000	3,120	4,285	36,000	47,800	482,417
Contra Costa.....	75,000	34,468	42,640	383,760	201,518	2,972,130
Del Norte.....			1,056	9,450	120	
Eldorado.....	6,390	26,400	77,472	697,248	1,441,039	581,342
Fresno.....	2,000	1,000	3,000	27,000		40,687,207
Humboldt.....	800	500	915	8,235	839	4,095
Inyo.....					252	39,478
Klamath.....		1,000	2,000	18,000	2,917	
Lake.....					11,000	296,752
Lassen.....					200	31
Los Angeles.....	726,000	600,000	1,650,000	14,850,000	3,000,000	4,923,877
Marin.....		500	600	5,400	11,542	115,198
Mariposa.....	1,000	15,227	15,000	135,000	51,783	28,647
Merced.....	10,000	15,000	15,000	135,000	100,740	1,281,342
Monterey.....	10,000	11,650	50,000	50,000	84,839	79,935
Napa.....	22,700	55,000	90,000	810,000	1,166,935	8,595,338
Nevada.....		6,000	8,000	72,000	124,000	94,338
Placer.....	2,702	5,742	5,000	45,000	397,101	1,340,132
Plumas.....		800	400	3,600	1,616	
Sacramento.....	52,200	119,500	327,900	2,951,000	951,315	7,627,510
San Bernardino.....	80,000	38,000	75,000	675,000	312,562	987,127
San Diego.....	4,000	4,000	50,000	450,000	1,915	1,228,858
San Francisco.....		1,200	1,000	9,000	75	3,000
San Joaquin.....	13,467	28,640	40,000	4,112,792	493,387	13,371,794
San Luis Obispo.....	1,500	2,000	10,000	90,000	18,263	265,481
San Mateo.....	5,000	40,000	40,000	360,000	16,000	124,990
Santa Barbara.....	15,000	70,000	90,000	810,000	220,000	208,595
Santa Clara.....	150,000	500,000	513,000	4,617,000	2,000,000	5,584,480
Santa Cruz.....	5,000	6,179	20,000	56,000	218,100	1,365,418
Shasta.....	5,348	6,100	25,000	225,000	1,534,520	117,481
Sierra.....		1,900	3,500	31,500	4,737	
Siskiyou.....	1,000	1,000	2,000	180,000	8,469	2,473
Solano.....	56,178	50,000	52,869	554,178	950,600	1,213,265
Sonoma and Mendocino.....	61,590	170,508	187,621	2,000,000	2,830,195	18,864,163
Stanislaus.....	4,420	3,020	1,800	162,000	112,310	1,932,302
Sutter.....	45,123	135,369	50,000	450,000	163,663	1,249,923
Tehama.....		2,000	5,500	49,500	145,883	1,307,218
Trinity.....	150	1,717	1,151	10,359	19,096	2,842
Tulare.....		400	30,000	270,000	100,950	7,227,491
Tuolumne.....	9,858	29,891	57,520	517,734	505,250	95,811
Yuba.....	26,902	61,903	155,425	1,398,825	157,434	2,568,019
Yolo.....	28,000	30,000	50,000	450,000	494,472	162,751
Alpine.....						9,000
Glenn.....						20,416
Imperial.....						298,813
Kern.....						419,582
Kings.....						4,538,732
Madera.....						795
Modoc.....						2,000
Mono.....						282,682
Orange.....						1,570,794
Riverside.....						177,976
San Benito.....						1,530,630
Ventura.....						36,398
Total number of vines.....	1,540,134	2,265,062	3,854,548	40,172,654	19,695,814	139,099,560
Total acres.....			11,411	59,077	28,966	

At this earlier period the pioneer growers of grapes were beginning to realize the possibilities of success due to the advantage of the peculiar suitabilities of climate and soil in California for the culture of European varieties of *Vitis vinifera*.

Within the period of 48 years (1866-1914) there had been an increase of nearly 90,000,000 vines. Within this lapse of time, so comparatively short for such a prominent industry of the State, many changes occurred in the different viticultural districts with which phylloxera had little or nothing to do, and the gradual damage and loss caused by the insect could not be compared with the acutely sinister influence of extreme fluctuations in the market values of grapes, whether for wine, raisin, or table use, which swayed the industry at different times from opulence to ruin and vice versa for the growers; yet when looking backward over the years, the phylloxera stands out preeminent and is considered as the main single factor in the loss and damage sustained by California viticulture.

In the early period the counties south of the San Bernardino boundary line were in the lead for the acreage in vines and for the production of wine. To-day in these counties viticulture is of secondary importance, yet phylloxera has never been discovered there. The Anaheim disease was one of the causes of this decline, but the change to the more lucrative investments in citrus culture, which no doubt appealed more to the tastes of the many eastern settlers who largely populated that portion of the State, is mainly responsible for the falling off in acreage of grapes and lack of interest in the industry.

Another viticultural district which underwent a great change was that of the Santa Clara Valley. There grape growing increased rapidly from 1885 to 1895, when the acreage of vineyards was the greatest and the county of Santa Clara produced almost one-third of the dry wines of the State. From 1893, when the vines began to die, the decline in acreage was much more rapid than had been its growth.

It was commonly believed at the time that the Anaheim disease, which had caused such great ravages in the southern part of the State, was also responsible for the sudden dying off of the vines in the Santa Clara Valley. The damage caused to the vineyards was so extensive that an investigation was instituted by the College of Agriculture of the University of California to determine the cause (3). The general conclusions arrived at were the following:

First, that the dying vines exhibit symptoms differing materially from those shown by the vines in Southern California which were destroyed by the Anaheim disease; and, second, that whether or not there be some "unknown influence" at work, as suggested by Mr. Newton B. Pierce, the real, determining factor is the deficiency of rainfall during the years 1897-1900.

At this time the phylloxera was known to exist more or less throughout the valley, and had been identified in different vineyards, but as yet its injury had not reached the advanced stage of noticeable characteristic phylloxera spots, was therefore little in evidence, and was not considered a prominent factor in connection with the destruction of the vineyards.

The following facts were brought out during the writers' investigations and have a direct bearing upon existing conditions in the Santa Clara Valley at that time:

Extensive areas of a vineyard may be infested by phylloxera before characteristic spots are noticeable; a lighter crop and a slight decline in vigor of growth are for some time the only apparent signs of injury.

Infested vines change suddenly for the worse, becoming rapidly stunted in growth, or even dying, when influenced by unusual conditions either from lack or excess of moisture.

Injured roots, functioning poorly under normal conditions of moisture, reproduce with difficulty fibrous roots, or feeders, to replace those which have been destroyed by the insect, and when subjected to drought they starve the vine.

Excessive moisture, instead of benefiting injured roots, causes them to rot and hastens the death of the vine.

For these reasons it is believed that the phylloxera was responsible for a far greater share of the destruction of the Santa Clara Valley vineyards than has been ascribed to it.

While Santa Clara and the southern counties have lost in acreage, a larger gain has been made at about the same period and later in other counties, especially those of Sutter, San Joaquin, and Fresno. Many vines throughout the State have been killed by phylloxera and not replanted; more have been grubbed out and replanted, sometimes more than once, and it is estimated that the loss in these respects has been very considerable.

Mr. George C. Husmann, pomologist in charge of viticultural investigations, Bureau of Plant Industry, United States Department of Agriculture, estimates the loss at 75,000 acres; Prof. F. T. Bioletti, of the viticultural department of the University of California, makes a similar estimate; and Charles C. Wetmore, for many years identified with the board of State viticultural commissioners, considers this estimate conservative.

VINEYARD DESTRUCTION.

PROGRESS OF THE DESTRUCTION OF A VINIFERA VINE.

According to conditions there is a great variation in the number of months or years that elapse between its original infestation by

phylloxera and the actual death of the vine. The following points have important bearing on this:

Soil conditions and drainage.—From a survey made throughout the different districts of California, the following general statements can be made in regard to the destruction of vineyards when the vines are 8 to 10 years of age or older before becoming infested:

Vines live longer in rich, deep, well-drained soils. Under such conditions, vineyards known to have been infested for 20 years and longer still bear crops, have only a few vines actually dead, and but a small percentage bearing little or no crop.

Vines die sooner and the crop of the vineyard is more rapidly diminished in quantity and quality when established on rich soil only a few feet deep and with poor drainage, or on side-hill soils lacking moisture.

Vines are still more rapidly affected in heavy soils, more or less shallow, with compact clay subsoil. In such types of soil, the vines, more or less stunted and enfeebled, may live a number of years. After a winter of unusually heavy rainfall they may show a very rapid serious decline or even a majority of them may die within a year.

Vines growing in a well-drained, very loose, and friable sandy soil, or one with a surface of blow sand several inches in depth, seem to be almost immune to the attack of phylloxera.

As a sandy soil becomes heavier in texture and of poorer drainage, so the vine succumbs more readily to the attack of the insect.

Age of vine at infestation.—Young vines are destroyed more readily during the first three years, before they have established a fairly good root system. When vines are 8 or 10 years old the quality and texture of the soil become main factors, and the more or less rapid destruction of the vineyard depends on the adaptation of the vine to the soil and the advantages of proliferation and diffusion for the insect. The general experience has been as follows:

Cuttings infested in their early growth rarely survive the first year.

Rooted vines, infested from the time of planting, produce from the start a very poor vineyard, which rarely lasts more than three or four years, the individual infested vines living after infestation hardly more than two years. If vines become infested during the second or third year from planting, they may last longer if they have a good root system, and in this case the vineyard may produce one or two crops smaller than normal and perhaps last five or six years. When a vine is three years old or more before infestation, its longevity depends somewhat on variety, much more on age, and especially on soil conditions.

Too few American varieties, either nonresistant or resistant, are grown in the State of California at this time to have been considered in this investigation.

Intrinsic vigor of vines.—Vines of great intrinsic vigor always resist phylloxera attack better than naturally weak plants.

Varieties of vines.—Amongst vinifera varieties grown in California, a few have shown certain resistance when inoculations have taken place several years after planting. Such are, in order, Flame, Tokay, Mission, and Muscat (Fresno district), and in a lesser degree Grenache, Chasselas, and Burger. Laboratory tests with certain varieties in which phylloxera lesions rotted rapidly have shown that Zinfandel, Thompson's Seedless, Carignan, Burger, and Muscat succumbed more rapidly and Tokay and Grenache less rapidly.

Destruction of a highly susceptible vine.—Under favorable conditions for rapid phylloxeration, the hypothetical progress of destruction of a highly susceptible vine, as Zinfandel, with established roots may be set down as follows: During summer and fall a few larvæ settle on a part of the root system; the following year infestation spreads to the surface fibrous and fleshy roots, and to a certain extent to the large roots near the crown, and nodosities and tuberosities are formed. The third year the subterranean infestation spreads pretty well throughout the root system, although it is rare to find year-old wood much attacked, for it appears that the habit of roots of this age to slough the outer layer of bark prevents the phylloxeræ from retaining a hold, and compels those already settled to move to other more hospitable portions of the root system. In this year some of the larger roots decay under combination of phylloxera attack and excessive moisture in the subsoil or become dried out from phylloxeration combined with too great drought, and thus the flow of sap between the feeding rootlets and the aerial portion of the vine is more or less cut off. This results in a shortening of cane growth and sometimes in an abnormally large crop of grapes. During this third summer as the larger roots die an emigration of young larvæ takes place. Many winged forms also may be developed. The fourth year finds the larger roots in great part destroyed, the cane growth correspondingly reduced, and a large number of fibrous and fleshy rootlets sent out from the trunk just below the soil surface. The phylloxeræ colonize these rootlets in spring, but leave them in summer, when they decay. There is also a heavy migration from the decaying roots farther down in the soil. In the autumn it is hard to find phylloxera on such a vine, and this explains the maxim that the best type of phylloxerated vine on which to look for the insect is not one badly stunted, but rather one with slight stunting of the canes; in fact, one in the

second or third year of phylloxeration. Such a vine as has been portrayed generally dies in the fifth or sixth year from the initial attack.

As has been pointed out above, the decline of a vine is influenced by many conditions, and the hypothetical case given shows the minimum longevity of an established susceptible vine after phylloxeration. Under favorable conditions infested vines live much longer, and in extreme cases their length of life seems hardly affected by the continued presence of the insect on their roots, a slight decrease in the size of the crop being the only evidence of injury.

HOW THE PRESENCE OF PHYLLOXERA IS INDICATED.

The existence of the phylloxera in a vineyard is indicated by the well-known areas or "oil spots," so termed because of their manner of spreading. A "spot" appears first in the form of one or two vines showing a slight shortening of the canes and a premature seasonal yellowing of the leaves, although the latter symptom may be caused by the red spider (*Tetranychus bimaculatus* Harvey), or by alkali in the soil. The year following this indication the vines originally infested exhibit a more noticeably stunted appearance, while other vines surrounding them show slight shortening of canes and premature discoloration of foliage. After this the "spot" increases in size, in course of time the vines in its center die, and finally the vineyard may become totally destroyed. The writers have never observed the "spots" to increase as rapidly in California as they are reported to have done in the vineyards of France after the time the insect first reached that country, when 2,500,000 acres were destroyed in 25 years, and vineyards frequently have been observed in California which had phylloxera "spots" of more than 20 years' standing to have vines still living.

The "oil spot" generally is circular in shape, but sometimes it assumes other forms. At times it is oval or narrowly elongate, the latter form occurring on hillside vineyards through which water rills run in the spring. In such cases spread of the "spot" is often rapid in a downward direction, indicating that running water is an extra factor in the spread of infestation. The writers have demonstrated by experiment (see "Diffusion of phylloxera," p. 100) that the phylloxerae can be carried in water from one vine to another, and when the rains of March and April occur there are plenty of active phylloxerae on the roots. In other cases the spread of a "spot" follows the direction of the prevailing winds and it appears that this spread is caused by wind agency in the transportation of wandering larvæ in summer and autumn. In vineyards where vines are planted rectangularly (i. e., 8 by 12 feet), instead of square, the infestation

very frequently spreads along the shorter 8-foot rows, indicating that the insects traverse more easily the shorter than the longer distances. Aerial and subterranean migrations of wandering larvæ play an important part in the enlargement of phylloxera "spots." Only an infinitesimal percentage of the thousands of wandering larvæ succeed in reaching their goal, but, as they are parthenogenetic radicles, a single larva can cause a new infestation or start a new "spot" at quite a distance from the original one, either in the same or in another vineyard.

The estimation of root injury from external appearance usually can be made with considerable accuracy, and the degree of infestation of a vineyard computed by the number of "spots," their size, and the stunted condition of the vines composing them.

The diagrams (figs. 2 and 3) indicate a phylloxera "spot" charted, respectively, in the years 1914 and 1915. This "spot" occurred on a heavy black clay soil on a hillside of moderate slope. It appeared that the "spot" started about the year 1907 when the vines were 3 years old, and that the first vines died about 1911. Surveys of the "spot" were made October 13, 1914, and November 5, 1915, and the vines were designated in the following manner: Ten was given to vines which showed no external evidences of phylloxeration; 9 to those which showed very slight evidence, such as premature yellowing of foliage and slight shortening of canes; 8 to those showing more advanced symptoms of phylloxeration, and so on down to 1, which was given to vines which showed only the most feeble vegetative growth. In order to portray the "spot" more vividly, symbols have been utilized as follows: Healthy vines, *H*; vines designated 9 and 8, *S*; vines designated 7 and 6, *I*; vines designated 5 and 4, *U*; vines designated 3, 2, and 1, *D*; vines killed by phylloxera, solid dot. In this vineyard every fourth vine had been replaced by a walnut tree, and these places where vines have been pulled out and not replaced are left blank in the diagrams.

In the diagrams not all the "spot" is shown, for it has extensions, the principal one being on the north side across a 24-foot avenue and continuing down a swale for some 60 feet. Enough of the "spot" is shown to indicate its general form. Between 1914 and 1915 there occurred an unusually wet winter and the "spot" grew considerably in the 12 months between the surveys. Although the number of dead vines increased only from 43 to 49, and among the badly stunted types not much increase was shown, there was a marked increase in the number of vines showing recent phylloxeration.

When more than one variety of vine is included in a "spot," a good index of the resisting power of the several vinifera varieties frequently is observable. Among the dead or moribund vines of

the susceptible varieties stand out the more vigorous vines of the less susceptible kinds or even individuals of the same variety.

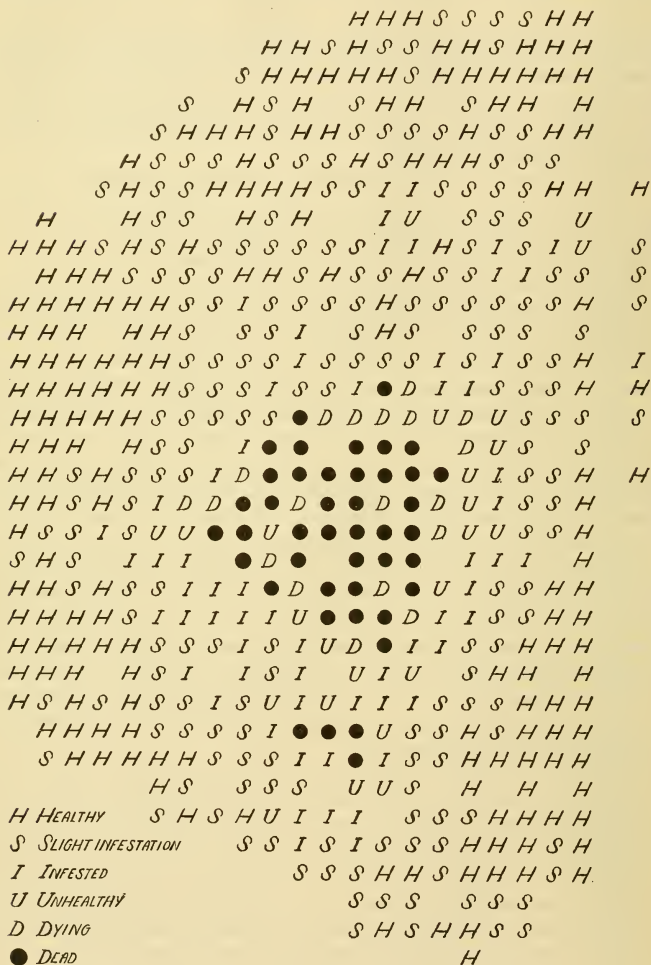


FIG. 2.—Phylloxera "spot" in Zinfandel vineyard, charted in 1914. (See text.)

The year previous to showing a marked decline, vines frequently bear an unusually abundant crop of grapes, and stunted vines seem to produce a larger amount of grapes in comparison to the size of



FIG. 1.—Young raisin vineyard uninfested by Phylloxera.

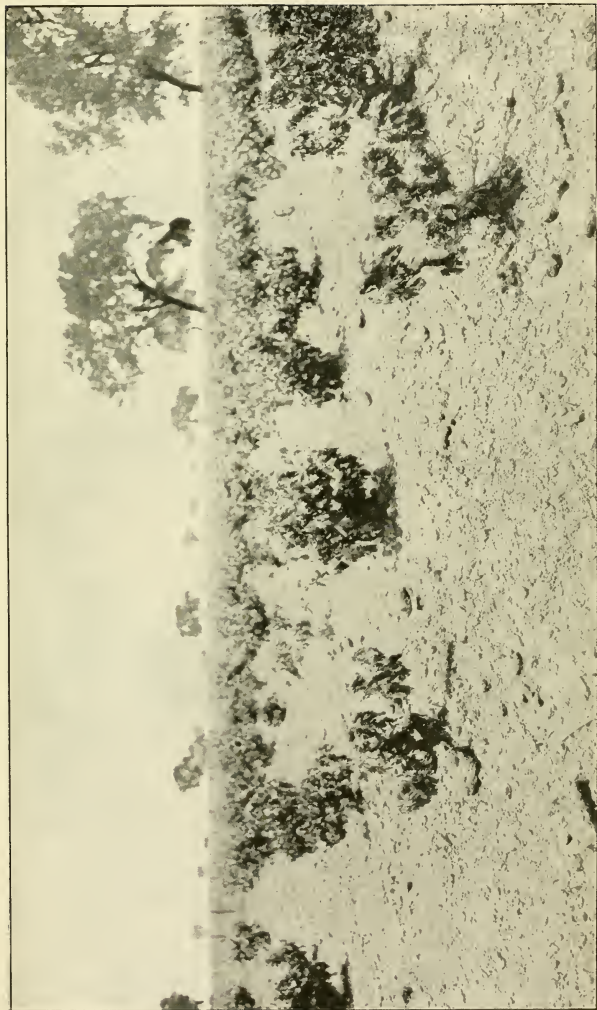


FIG. 2.—Old vinifera vineyard infested throughout with Phylloxera and showing empty spaces where vines have been killed; vine in foreground shows less infestation by Phylloxera than others near by, and would be rated at 7, but the canes show obvious stunting.

THE GRAPE PHYLLOXERA IN CALIFORNIA.

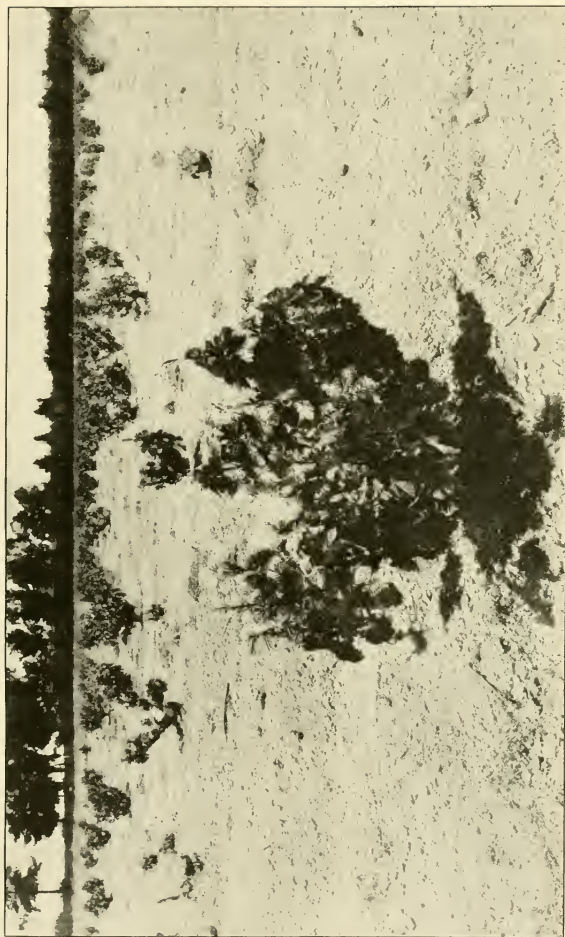
CORRECTION SLIP FOR DEPARTMENT BULLETIN 903

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Cut reproduced as Pl. III is Pl. I, fig. 2.



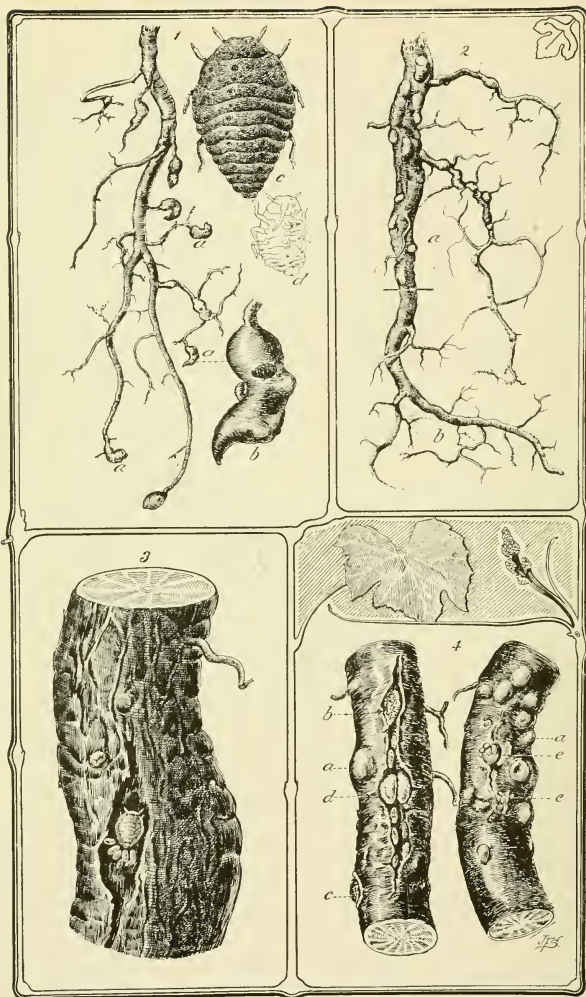
THE GRAPE PHYLLOXERA IN CALIFORNIA.

Old Tokay vineyard with Phylloxera infested "spot" in foreground; vine in central foreground to be rated at 6; the two vines on sides in foreground to be rated at 3 on the scale of Phylloxera injury.



THE GRAPE PHYLLOXERA IN CALIFORNIA.

Old vinifera vineyard infested throughout with Phylloxera, and showing many empty spaces where vines have been killed. None of the vines in the foreground is to be rated above 3 on the scale of injury from 1 to 10.



THE GRAPE PHYLLOXERA IN CALIFORNIA.

Phylloxera vitifoliae: Fig. 1.—Phylloxera nodosities shown on Zinfandel grapevine: *a*, Nodosities on terminal rootlets; *b*, nodosity showing *Phylloxera* feeding; *c*, adult louse; *d*, molted skin of same. Fig. 2.—Phylloxera tuberosities on smaller root: *a*, Infested portion of root; *b*, normal portion of root. Fig. 3.—Section of grapevine root showing adult louse with eggs *in situ*. Fig. 4.—Sections of root infested: *a*, Newly formed tuberosity; *b*, advanced stage of tuberosity; *c*, side view of older form of tuberosity; *d*, tuberosity causing the cracked condition of bark; *e*, young colony of insects as found on roots.

their wood growth than do healthy ones. Such grapes mature, however, without attaining a good size or their normal saccharine con-

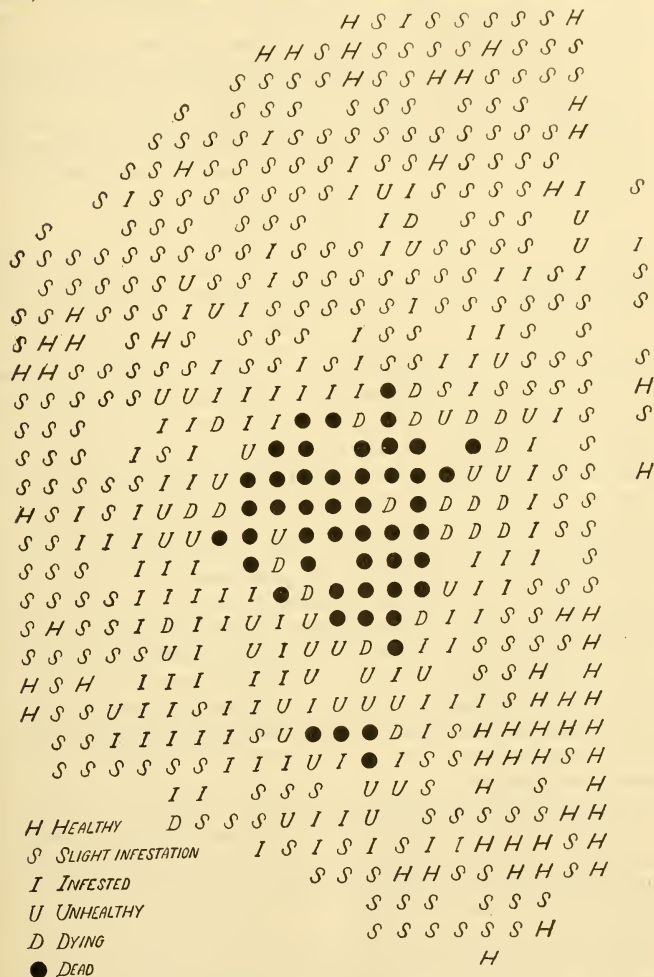


FIG. 3.—Phylloxera "spot" in Zinfandel vineyard, charted in 1915. Same "spot" as shown in figure 2. (For description see text.)

tent. Stunted vines produce leaves of a more uniform size than healthy vines, and because the internodes of the canes are shorter, the leaves appear more closely grouped, giving the "cabbage-head"

appearance to the vines. Scarcity of rapid-growing terminal shoots and absence of tendrils are characteristics of stunted vines. Plate I, figure 1, shows a young vineyard which is uninfested and in which the vines have made normal growth. Plate II shows a small phylloxera "spot" in an old vineyard, the photograph showing stunted vines in the foreground. Plate III and Plate I, figure 2, indicate badly infested old vineyards, in which all the vines are phylloxerated and most of them badly stunted. The vine in the foreground of Plate III is obviously stunted, although less so than its neighbors.

PHYLLOXERA ROOT LESIONS.

Root lesions are swellings on grape roots caused by the puncture of the phylloxera beak. They are of two types, (1) nodosities and (2) tuberosities.

The nodosity.—Nodosities (Pl. IV, fig. 1) are rapidly growing swellings on the white fleshy feeding rootlets. They soon acquire a characteristic greenish-yellow color, and curve and bulge around the phylloxera responsible for their inception so that the insects come to lie in a depression (Pl. IV, fig. 1, *b*). A nodosity may become as much as six times the diameter of the normal size of the root when several insects have settled upon it, and about twice the diameter for a single occupant. Through its size, form, and color, the nodosity is very conspicuous in comparison with the root and is manifest proof of the presence of the phylloxera.

In most cases the formation of a nodosity arrests the growth of the rootlet. At times the rootlet grows one-fourth inch or so in length, and occasionally the puncture of the phylloxera does not affect the rootlet in its growth, the subsequent swelling acquiring a lignous character and becoming a tuberosity. Nodosities are generally short-lived, lasting about a month. Excess moisture hastens their decay, lack of moisture dries them up, but a low, even temperature causes them to last longer.

The foregoing also applies to the American variety of vines styled nonresistant. On the rootlets of the resistant American vines the phylloxera frequently fail to cause swellings, and when nodosities are produced they are smaller, less fleshy, and brown in color. At times, though no swelling occurs, the rootlet dies at the point of puncture.

The tuberosity.—Tuberosities (Pl. IV, figs. 2, 4) also are swellings caused by the puncture of the aphid. Though of a similar nature, they differ from nodosities in form because of the lignous character of older roots. They occur on all parts of the root system of vinifera vines except at the apex of the growing fibrous rootlets. They may

also occur on the trunk of the vine, both above and below the soil surface. They are less commonly formed on roots of one year's growth than on older wood. On resistant vines tuberous swellings are normally quite unusual, but they may be formed on the healing growth of the cambium layer about an abrasion. On most American vines of nonresistant type, tuberosities are abundantly formed. On vinifera $\times$ resistant hybrids the more the resistant strain predominates the scarcer are the tuberosities.

Tuberosities are formed at any time between March and October, most abundantly during the summer months. They are formed more readily on vigorous roots than on those somewhat dried or decayed. Hibernants often choose tuberosities upon which to pass the winter, besides inducing their growth at points as yet sound and uninfested, the mere insertion of the beak being sufficient to stimulate growth. Tuberosities vary considerably in their general appearance, even on the same vine. Some are minute papillæ on the surface of the root. Others are large, fleshy, rapidly growing, globular outgrowths, as much as half an inch in diameter, and this type is found chiefly on the smaller roots. Others are enlargements of the girth of the root at intervals, a type also confined to small roots. Others consist of more or less uniformly rounded swellings of one-sixth to one-fourth inch diameter on the root surface, and these are the ones most commonly found on larger roots. Such tuberosities by their growth generally split the epidermis of the root longitudinally, and as the split tends to lengthen at both ends, the tuberosity assumes an oval or elongate shape. Later, when the split enlarges, fresh tuberosities are formed by aphids on the inner layer of bark exposed by the split, and shortly a chain of lesions occurs along the crack. These cracks lengthen and often involve a length of more than 6 inches. On roots growing horizontally or almost parallel to the soil surface, the majority of the tuberosities will occur on the lower side, the insects apparently settling there because of the greater moisture. On vertical or sloping roots tuberosities occur more or less uniformly all around. As long as they remain fresh, tuberosities provide an excellent quality of food for the aphids. This condition should be distinguished from the rapid development observed in the case of aphids settled on root callus, which forms at the point of severance and is caused by the action of the healing cells of the cambium layer becoming greatly enlarged and very fleshy, furnishing excellent food for the aphids, through the natural function of the wounded root.

Many factors influence the length of existence of tuberosities. In general, it is found that those formed in the autumn will last until the rainy season, and commence to decay immediately afterwards.

Their decay is expedited by a heavy rainfall and a high-water table. Those formed during the spring and summer in a moist environment rarely persist fresh beyond two months, and most of them decay about one month after they arise. It has been repeatedly observed how quickly a fresh tuberosity decays when it is placed against wet sand, and if a stream of water finds its way down a root the tuberousities thereon start to decay immediately. On the other hand, they are more capable of withstanding dry soil conditions than are the nodosities, and under conditions approaching drought, which sometimes occur in late summer and autumn, may last for a considerable time and even lignify, the dry environment having caused the insects settled on them to seek more favorable conditions of moisture and at the same time having kept in check decomposition. Tuberousities withstand a considerably greater range in temperature than do nodosities, and they are not affected by sudden changes in temperature in the same manner as are the nodosities.

Tuberousities grow larger and more rapidly in proportion to the soundness of the roots. On roots previously uninfested the growth of the swellings is rapid and vigorous, and a root, after it has been heavily phylloxerated for several months, becomes so greatly exhausted that it can not respond to the punctures of the aphids by developing new swellings, and the phylloxeræ that are not gradually driven away to seek more nutritious food develop on the root without causing swellings. The decay of the tuberousities begins at the place first punctured by the aphids, generally at about the center of the swellings. The tuberosity forms around the insect, and decay is first evident as a small, blackened spot, sometimes exuding a liquid. The rapidity of decay of tuberousities is in proportion to the increasing moisture content of their environment, and in an unusually dry environment they frequently will lignify without causing the tissues to rot. Under moist conditions the inflated cells rapidly break down and decay usually spreads, and fungi and molds enter the tissues, especially in the case of large bulbous swellings. Decay finally drives off the aphids, but through their stimulating action they are often able to retain the freshness of a tuberosity for some time after it has been surrounded by decayed tissues, and occasionally a fresh, vigorous specimen is found on a root otherwise quite decayed. The nutritious quality of these tuberous lesions provides for the production of nymphs in great numbers.

HOW ROOT LESIONS AFFECT THE HEALTH OF VINES.

It has been shown in the foregoing pages that the nodosities are those phylloxera lesions formed at the apex of growing fibrous rootlets, whereas the tuberousities are lesions formed on all other parts

of the root system. Since the vine derives its plant food through the growing rootlets that thrust their way through the soil, it is obvious that when such rootlets rot as a result of the decay of the nodosities situated on them no more sustenance can be afforded the plant through this medium. If, on the other hand, the rootlets continue to grow notwithstanding the nodosities situated on them, and if the nodosities lignify, the supply of nourishment provided by the rootlets is not cut off, and the nodosities become in effect tuberosities. This is often the case with resistant vines, and much more rarely with vinifera or nonresistant Americans. In resistants these tuberosities generally lignify and heal, but in the other types of vines they do this only if their environment is quite dry. Nodosities effectively destroy the terminal rootlets; but since the insects spread very slowly on resistants, a vine of any vigor has abundant feeders, and thus it follows that resistant vines bearing very few or no tuberosities, but having many nodosities, do not succumb to phylloxera. Resistant vines never lack the power to produce enough feeding rootlets to sustain them as long as the following conditions, which are normal to these vines, obtain: (1) When the development and spread of the phylloxera on them are comparatively slow; (2) when a large percentage of insects that have been raised on the nodosities become nymphs and later leave the roots as winged migrants, in an endeavor to reach the surface of the ground or the aerial parts of the vines. Both of these conditions may be affected by the quality of plant food, as will be shown. Instances have been seen in which young resistant vines have been rid of their entire infestation because all of the immature phylloxera became winged migrants in the autumn, but in the majority of cases of infested resistant vines under observation there remained in late fall a small wingless infestation, and in some instances where the vines had been growing in small pots with insufficient nourishment infestations of wingless aphids persisted, and the production of winged migrants during the autumn was proportionately small. These wingless infestations, however, were not prolific. It appears that thrifty resistant vines afford poor nourishment for phylloxera, and they do not respond to phylloxeric irritation by producing swellings. When, however, resistant vines become weakened through a poor supply of plant food, the phylloxera attacking them persist and the vines respond to the phylloxeric irritation and form lesions.

Although the decay of the nodosities on vinifera vines destroys the feeding rootlets, this in itself is not a potent factor in the destruction of the vines by phylloxera. Except under abnormal conditions, such as the confinement of vines in pots with impoverished soil, no case has ever been observed in which the death of a vine could be attributed solely to the decay of nodosities, whereas instances have

been observed wherein vines flourished with their vitality but slightly impaired, notwithstanding a nodositous infestation extending over several years. One such instance was that of a 20-year-old vineyard of Burger and Chasselas (*viniferae*) near Napa, Calif. In 1913 the vines had been phylloxerated for upward of eight years, and each year the nodosities had been extremely abundant and practically no tuberosities had been developed, yet the vines appeared quite thrifty, owing to the maintenance of a sufficient number of uninfested feeders. It is the decay of the tuberosities on the larger roots, which the vine can not replace, that causes at first the impairment of the vine's functions and later results in its death. The simultaneous decay of many tuberosities is the cause of rapid decline in the vigor of a vine and is the prelude to the vine's death. The larger roots near the crown of the vine are especially susceptible to tuberositous decay, while the decay of a root below the crown is often very slow. This lower portion under favorable conditions is able to maintain itself undecayed for months, if not years, and is capable of providing nourishment for phylloxerae. It is frequently observable that vines retain their vigor despite a ring of decay at the crown of the roots, and do not become stunted until the major portions of the larger roots have rotted.

In a discussion of the effect of root lesions on the health of vines, emphasis should be placed upon the decay of the tuberositous lesions and upon the fact that this decay is invariably hastened by moisture and retarded by dryness. Decomposition is often hastened by the work of fungi, molds, thysanurans, and tyroglyphid mites. The most common mite so working is *Rhizoglyphus elongatus* Banks, specimens of which were determined by Mr. Nathan Banks. It is a rather large species and is very prevalent throughout the grape sections of California. It was frequently reared on decaying roots kept in the cellar of the laboratory. The mite is hyaline white, with two brown circular spots, one behind the other, on the dorsum of the abdomen.

NOMENCLATURE AND SYNONYMY OF THE GRAPE PHYLLOXERA.

The genus *Phylloxera* was erected in 1834 by Boyer de Fonscolombe (10). The type species is *P. quercus* de Fonscolombe. In 1856 Asa Fitch (9) described the grape-leaf gall louse as *Pemphigus vitifoliae*. The species was obviously placed in the wrong genus. In 1867 Shimer (21) erected a new family (*Dactylosphaeridae*) and a new genus, *Dactylosphaera*, for a new species of his (*globosum*) and tentatively placed *vitifoliae* Fitch in this new family and genus. In a footnote he also proposed the genus *Viteus* for Fitch's insect. In 1868 Planchon (20) described the grape root louse from France as *Rhyz-*

aphis vastatrix Planchon, and in the same year Signoret (22) placed the species *vastatrix* in the genus *Phylloxera* de Fonscolombe. The year following Westwood (23), in England, described the insect as *Peritymbia vitisana*, but in a later article the same year he placed his species in synonymy as follows: *Peritymbia vitisana* Westwood = *Pemphigus vitifoliae* Fitch. *Dactylosphaera* (?) *vitifoliae* Shimer, and *Phylloxera vastatrix* Planchon (19). Until 1900 the name generally recognized by writers had been *Phylloxera vastatrix* Planchon. In 1900 Del Guercio (12), in Italy, erected the genus *Xerampelus* to receive the grapevine species, which he therefore called *Xerampelus vastator*. This genus has not been recognized by all later authors. Grassi (11, p. 12) would retain Shimer's proposed genus *Viteus* as a subgenus to *Phylloxera*, and would thus name the species *Phylloxera* (*Viteus*) *vastatrix*. The present writers are inclined to retain the specific name *vitifoliae* Fitch on account of its evident priority over Planchon's more widely known *vastatrix*, and notwithstanding the objections raised by authors as to its orthographical correctness (*vitisfolii* and *vitifolii* have been preferred and written). As to the generic title, it has been decided that *Phylloxera* will be retained, the question of the subdivision of the genus being left to those who have had more opportunity to study the specific ramifications of this group.

The synonymy of the grape phylloxera as understood by the writers is therefore as follows:

***Phylloxera vitifoliae* (Fitch).**

Pemphigus vitifoliae Fitch, 1855-56.

Dactylosphaera (?) *vitifoliae* (Fitch) Shimer, 1867.

Viteus vitifoliae (Fitch) Shimer, 1867.

Rhysaphis vastatrix Planchon, 1868.

Phylloxera vastatrix (Planchon) Signoret, 1868.

Peritymbia vitisana Westwood, 1869.

Xerampelus vastator (Planchon) Del Guercio, 1900.

Viteus vastator (Planchon) Grassi et al. 1912.

BIOLOGY OF THE GRAPE PHYLLOXERA IN CALIFORNIA.

THE LIFE CYCLE.

The complete life cycle of the grape *Phylloxera* under natural conditions, i. e., on the wild vines of eastern North America, is extremely complicated (fig. 4). It is not the intention of the authors to enter into all the ramifications of this cycle in the present paper, but it may be said that the following are the main forms that occur: (1) The stem mother or fundatrix, which hatches in spring from the winter egg, ascends to an early leaf, settles on the upper surface, and causes to form around her a pocketlike gall opening on the

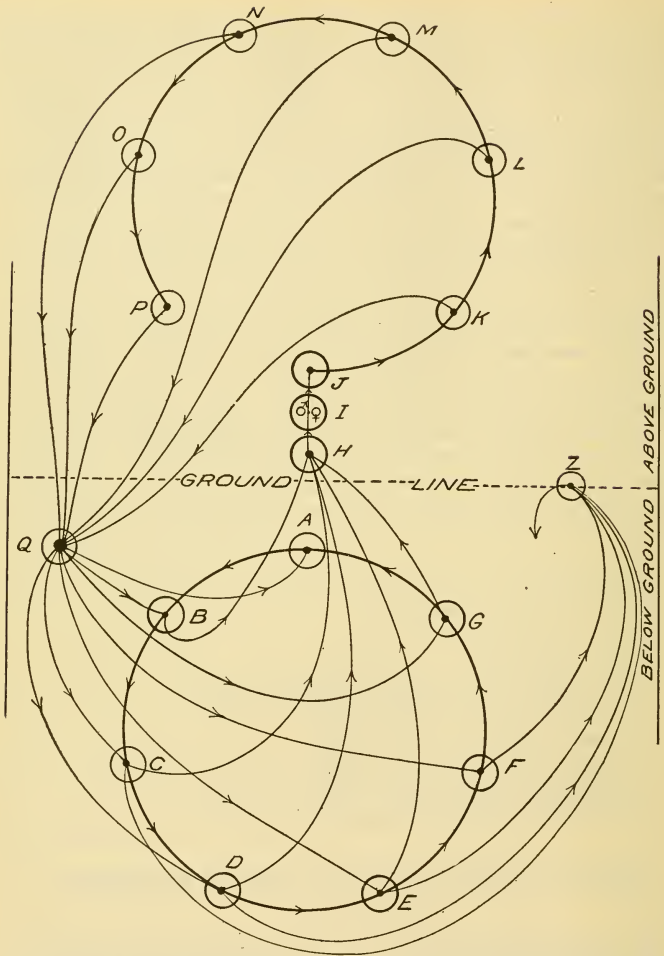


FIG. 4.—*Phylloxera vitifoliae*: Genealogical graph of the grape phylloxera in the eastern part of North America and in the Mediterranean regions. A, Hibernant radicicole; B-G, successive radicicole generations; H, winged sexuparous migrant; I, sexes; J, stem-mother gallicole; K-P, successive gallicole generations, part of the young larvæ of which proceed below ground (Q) to join the radicicole circle at various stages dependent upon the gallicole generation of which they were members; Z, emergence above ground of the wandering radicicole larvæ. In this figure, in order to avoid undue confusion, no account has been taken of the development in the galls of winged sexuparous migrants. Such development is unusual, but it indicates the possibility of a life cycle entirely aerial.

upper side of the leaf; (2) several parthenogenetic generations to which the stem mother gives rise, some of which settle on the foliage and produce new galls, as gallicoles, while others repair to the roots and settle on them as radicales; (3) parthenogenetic generations on the roots descended from the phylloxerae which went from the foliage to the roots; (4) winged migratory forms, comprising a very variable percentage of the root and gall forms, produced in summer and autumn, which fly or are transported by wind to other vines and oviposit either under the bark or on the leaves; (5) the true sexes, which are wingless and beakless; (6) the winter egg, deposited under the bark by the sexed female after coition; (7) radicales, born on roots in the late autumn, which pass the winter thereon as small hibernants, mature the spring following, and give rise to radicle generations which succeed one another during the summer and autumn. This, briefly, is the life cycle that occurs in parts of Europe where American vines are used for stock, and in the eastern and southern United States on the wild grapes and on varieties derived from them.

It will be observed that the winter may be passed in two forms—the winter egg and the hibernant, the former on the aerial and the latter on the subterranean or root portion of the vine. On certain wild grapes, as *Vitis riparia*, *V. rupestris*, and *V. berlandieri*, and on hybrids from these species, the former is the normal form, and hibernating larvæ are rare. On species like *Vitis labrusca*, *V. monticola*, and their derivatives, both forms may occur. On viniferæ (*Vitis vinifera*) the latter form is by far the more common. In the majority of European grape districts both forms occur, the former on American resistant vines and the latter on viniferæ, but in other localities, even where resistant vines are used, the winter egg is very scarce. These include certain regions of France and California, and it appears that in California the hibernant is normally the only form that passes the winter.

The suppression of the winter egg, and, therefore, of the succeeding gall form, brings about a modified life cycle in the California vineyard which may be briefly described as follows: (1) The hibernant radicle passes the winter as a larva on the roots and occasionally on the trunk beneath the bark. (2) The hibernant, when mature, gives rise to generations of radicales, and the aphids that issue from eggs in late autumn become hibernants. (3) A certain percentage of radicales, varying from causes such as humidity, temperature, condition of food, and variety of vine, develop into winged migrants and issue from the ground. (4) Radicle larvæ forsake the roots and seek to reach other vines either by way of the soil surface or through subterranean passages such as cracks.

The part of the life cycle from the sexes to the gallicoles through the winter egg and fundatrix is either omitted or does not proceed beyond the winter egg in California, notwithstanding the frequent

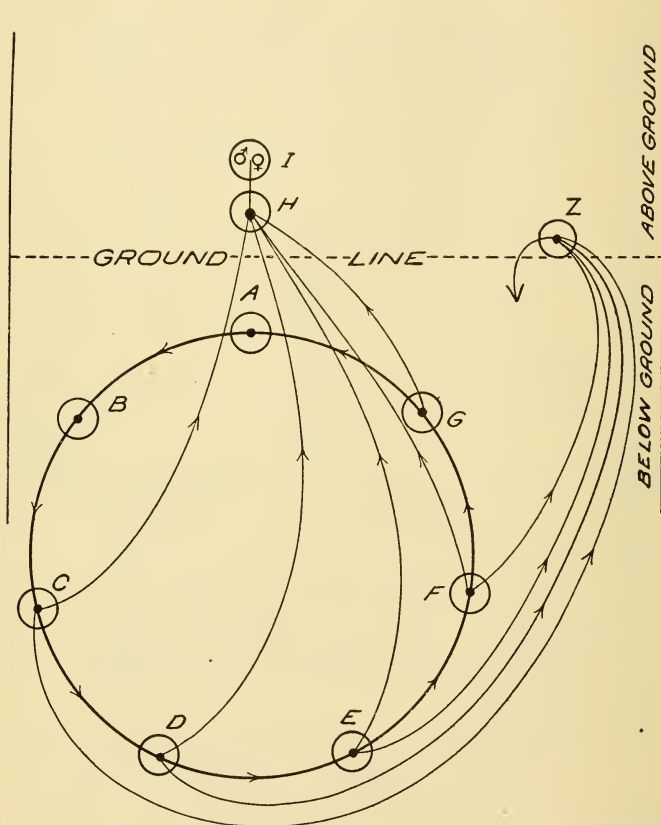


FIG. 5.—*Phylloxera vitifoliae*: Genealogical graph of the grape phylloxera in California. A, hibernant radicicole; B-G, successive radicicole generations; H, winged sexuparous migrant; I, sexes; Z, emergence above ground of the wandering radicicole larvae.

abundance of resistant types of vines, types many of which normally bear galls in other localities. The result is that the California cycle (fig. 5) is purely parthenogenetic and is therefore greatly modified from the original cycle (fig. 4) occurring on wild vines, the natural hosts of the insect.

RÉSUMÉ OF LIFE HISTORY IN CALIFORNIA.

A résumé of the life history will be presented before all the different stages and habits of the phylloxera in California are discussed in detail. This résumé is confined to the biology of the insect on viniferae and does not consider the life history on resistant roots.

Over 99 per cent of the phylloxerae pass the winter as small brownish unmolted larvæ, the remainder hibernating after having passed one or two molts. All parts of the root system are used for hibernating quarters, but the majority cluster on the larger roots, following an upward migration in the fall.

Coincident with the first sap flow in early spring is the growth of the hibernants, but in a given vineyard the earliest individuals commence to grow fully six weeks before the most tardy ones, so that after the foliage has opened, hibernating larvæ are still to be found on the roots. The development of the hibernants is considerably slower than that of the summer broods, and the former mature on the average about five and one-half weeks after they commence their spring growth. The development of the larvæ is at all times influenced by the quality of food and by conditions of humidity and temperature.

Upon casting its fourth skin, the hibernant is mature and commences egg deposition. Its progeny are the first-generation phylloxerae, and these on hatching from the eggs either settle beside the eggshell or go in search of new food. Many aphids settle on young growing rootlets and produce the fleshy swellings, termed "nodosities." Others settle upon older roots and produce swellings, termed "tuberosities." Still others develop on roots without causing the development of either perceptible swellings or lesions. Individuals feeding upon nodosities develop more rapidly than do those on the unswollen surface of the root. The nodosities usually decay within a few weeks after their formation, and in most cases the destruction of the rootlets follows. The tuberosities also usually decay in time. The rotting of the nodosities is not very serious, as the vine can supply new apical growth, but the decay of the tuberosities leads to the decay of the larger roots either wholly or in part, and as a result the vitality of the vine is greatly impaired, or the vine is killed outright.

The first-generation individuals are mature in from four to seven weeks after the eggs have been deposited, and they in their turn deposit eggs, which produce further generations throughout the summer and autumn.

Owing to the fact that, under favorable conditions, the adults deposit eggs during an average period of 45 days, an overlapping of generations ensues during the summer and fall. In order to avoid

confusion, it is assumed that there are five generations annually, since this number is about the average in a vineyard in which the sap moves early, although there might be, under certain conditions, from one to eight or even nine generations within a single year. The hibernant generation having matured in April, the succeeding generation matures about the time the canes have ended their first rapid growth, approximately the end of May. Succeeding generations mature on about the following average dates: Second, July 6; third, August 15; fourth, September 30; the fifth generation hibernating.

A variable percentage of the larvæ of generations 2, 3, and 4 becomes nymphs, and these later emerge from the ground as winged insects and either fly away or are borne off on the wind. Large numbers of these are caught in spider webs. Many of the newly hatched larvæ develop a wandering tendency just after they have issued from the eggshell and seek to emigrate to other vines either through the soil or over the surface of the ground. Large numbers of these migrating larvæ are also caught in spider webs on the surface, and while only a small percentage reach their destination, a single individual may start a new infestation. Those of the larvæ that succeed in fastening upon a root or rootlet develop as radicoles. The winged forms normally occur from June to October, and the wandering larvæ are found from July to September.

During July and August, when the adult radicoles are most prolific, incubation and development proceed most rapidly, and the phylloxera may be said then to have reached its most active stage. It is at this stage that the greatest damage is done to the roots of the vines, although the effects are not generally apparent until the fall and winter following, when the lesions formed during the summer have decayed.

At the end of September a few of the newly hatched larvæ hibernate, and throughout October successive generations become hibernants, so that by the end of the month a large majority of the phylloxera have reached this stage. During November and the first half of December, a few mature radicoles and growing larvæ may be found, but after the middle of December, it is unusual to find any form but the hibernating larva.

Under conditions of abundant food supply, the period of egg deposition of the radicoles averages 45 days and may reach a maximum of 110 days. This average is nearly constant throughout the season. The average number of eggs deposited is about 117, but under certain conditions the number may be increased to 486. The daily average number is about $2\frac{1}{2}+$ eggs, and as many as 23 eggs have been deposited in 24 hours by a single phylloxera.

The rate of egg deposition is usually indicated by a sharp rise shortly after commencement, followed by a gradual decline. During the period of egg laying the adult feeds, and after the last egg is laid may live for as long as three weeks.

Incubation naturally is influenced by temperature, and the duration of the incubation period may vary from five days in July to over a month in December. Very few eggs are laid in December, but in March and April, when many eggs are deposited, the maximum period of incubation is 27 days.

The larvæ mature in midsummer in about 15 days, and in April and November in about 34 days, and the hibernant generation develops in about 180 days. The winged forms mature more slowly than do the wingless individuals, since the fourth or nymphal instar is noticeably extended beyond that of the corresponding wingless stage.

In the late fall a few individuals intermediate in structure between the nymphs and radicles are found. These are called "nymphicals" or intermediates and, so far as is known, they deposit the same type of eggs as the radicles, although they are not prolific. From egg deposition to the molting of the final skin, the period covered by the sexes, which develop from eggs of two sizes laid by the winged forms, was about 12 days in confinement.

All stages of the phylloxera molt four times, and the first instar is always the longest (the adult instar excepted).

HIBERNATION.

The phenomenon of hibernation.—Throughout autumn and early winter an ever-increasing percentage of newly hatched radicle larvæ, instead of increasing in size and maturing normally, remain as very small brown phylloxeræ (Pl. IX, *d*, p. 64). As winter progresses, the mature individuals die, leaving only the small brown larvæ and a few unhatched eggs. As soon as these late eggs hatch, the larvæ settle down, becoming brown like the others. These small larvæ are the hibernants, and as such they remain throughout the dormant period. Occasionally phylloxeræ that have passed one or two molts hibernate. This type is quite unusual, and probably consists of individuals that have reached a certain stage of development and are unable, through lack of nourishment, to mature, most of them dying before spring.

Hibernant larvæ occur on all kinds of vines—on viniferæ and on American varieties and hybrids. While this form of phylloxera occurs more or less sparingly on American resistant vines (*Vitis riparia*, *V. rupestris*, *V. berlandieri*, etc.) and on some American

nonresistant $\times$ resistant hybrids, it finds its greatest development on viniferae and on certain American nonresistant varieties of *Vitis labrusca*, *V. aestivalis*, and *V. monticola*. On the wild species of *Vitis* of the eastern and southern parts of North America, considered as the original hosts of the grape phylloxera, is found a complicated life cycle embracing gallicoles (gall lice), radicales (root lice), winged migrants, sexed forms, winter eggs, and true stem mothers. The hibernants are rarely abundant on these wild species of vines, and the winter is passed chiefly in the winter-egg stage. On vinifera (*Vitis vinifera*) this complicated life cycle is rarely completed, and a simpler one, comprising only the root forms, obtains. Therefore, in the absence of the winter egg, the winter period must be tided over by another form, which is supplied in the hibernant larva. It appears that, to the phylloxera, *Vitis vinifera* is an acquired food plant, and that the nature and construction of the Old World grapevine has changed the habits and life history of the grape phylloxera feeding on it.

On viniferae, although hibernation takes place chiefly on the larger roots and on the subterranean portion of the trunk, it occurs also on nodosities and on smaller roots.

Hibernants are located both on lesions and on the normal surface of the roots. On the varieties of resistant vines and certain hybrids (vinifera $\times$ resistant and resistant $\times$ American nonresistant) that have been examined, it has been found that hibernation occurs chiefly on nodosities and less frequently on the normal root surface. Tuberosities rarely are formed on these vines. On American nonresistant and vinifera $\times$ nonresistant hybrids, hibernation was chiefly of the type found on the viniferae. On Golden Champion, Agawam, Catawba, Isabella, Lenoir, and Delaware, hibernants occurred on tuberosities, nodosities, and the normal root surface. On Moore's Early they were located on nodosities and on larger roots but not on tuberosities.

Appearance of hibernants.—The hibernants (Pl. IX, *d*, *e*, *f*, p. 64) appear as little oval brown insects flatly appressed to the surface of the root, their legs folded underneath the body. The antennae are borne at right angles to the major body axis, and hardly project beyond the maximum width of the body. The whole insect generally shows one color, but sometimes there is a darker median longitudinal line, except on the head. In those individuals which have molted before going into hibernation, a similar shade of darker brown occurs. Occasionally lighter individuals will be noted, but none is ever as pale as the growing and feeding radicle larvae. Hibernants located under several layers of bark, as a rule, exhibit a paler color than those living more exposed.

FIXATION OF BEAK.

To secure information regarding the fixation of the beak in the root five lots of hibernants were examined on January 23, 1914. The results are given below.

TABLE II.—*Fixation of beak of hibernants of the grape phylloxera.*

Lot No.	Number of individuals.	Number with beaks fixed.	Number with beaks free.	Remarks.
1.....	25	12	13	Under 2 layers of bark on large root.
2.....	25	21	1	Large root; insects originally under 2 layers of bark, but layers peeled off some time before experiment.
3.....	25	16	9	Small root; insects on tuberosities.
4.....	25	22	3	Do.
5.....	20	8	12	Under several layers of bark on stock of vine 3 inches below soil surface.
Total.....	120	82	38	

In lots 1, 2, and 5 the individuals that had their beaks fixed in the roots were obviously the more healthy. In lots 3 and 4 all the phylloxerae appeared equally healthy. They were on more succulent roots than those in lots 1, 2, and 5, and it may be that on such succulent food the hibernants have a habit of driving in and drawing out their beaks at will, whereas on harder roots this would not be possible. It is evident that hibernants situated on the outside bark of a root are likely to be washed off by water if their beaks are not inserted into the root. The experiment would serve to indicate that in the individuals of lots 1 and 5, wherein the hibernants were protected under layers of bark, the majority had their beaks free, while in lots 2, 3, and 4, wherein the hibernants were exposed, the majority had their beaks inserted, so that it appears that the fixation of the beak acts as an anchorage.

NOURISHMENT.

The hibernant larva partakes of nourishment very slightly, if at all, before it settles for the winter. During the period of true hibernation it apparently takes no nourishment. Therefore it is probable that the great majority of the hibernants take their first food when they arouse themselves from their lethargy in spring. Of those observed to feed before hibernating, a few pass one or rarely two molts, while the rest remain unmolted but larger in size than the true hibernating larva. The writers have observed instances in which severed pieces of roots infested by hibernants formed winter lesions, the presence of the beaks in the root affording a stimulus.

Hibernants on nodosities sometimes keep these fresh until spring by the stimulating action of their implanted beaks. Such nodosities, especially in *vinifera* and *labrusca* vines, otherwise usually fail to pass the winter in a fresh condition, as they are susceptible to rot through moisture.

DURATION OF INSTAR.

With the exception of the winter egg, the hibernant instar is the longest found in the life cycle of the phylloxera. A series of experiments undertaken in the laboratory during the winter 1911-12 showed that the average for 12 individuals was 183 days, or approximately half a year. A later series of experiments, which took place both on living vines and in the cellar on severed roots, indicated that this period may be shortened to four and one-half months and lengthened to seven and one-half months, dependent, as usual, on food, temperature, and moisture conditions, and that six months is about the average period for the development of the hibernants. This period was considered from the date in the fall on which the insect hatched from the egg to that on which the insect became mature the spring following. The actual state of dormancy is from three to six weeks shorter, and thus approximates five months. Granted that radicles may live for three months after reaching maturity, it is apparent that hibernating phylloxerae might attain a total longevity of over 10 months.

MOVEMENT ON THE ROOTS.

On a sound root, the overwintered phylloxerae rarely change their positions while they develop. If situated on tuberosities or nodosities, they cause these lesions to become enlarged, and if situated on the normal root surface they cause the formation of new lesions. Occasionally they develop without causing a lesion to appear. On decayed and decaying roots, they move away after the first or later molts and seek better food. This movement is both upward and downward, indiscriminately, and is never extensive. The individuals show only feeble inclination toward migration. This generation appears to be the lowest in vitality and the quickest to succumb to adverse conditions.

GROWTH AND MATURING OF THE HIBERNANTS.

During the true hibernation period the phylloxerae apparently take no food, and if any be taken no increase in growth can be noted. Later a slow but appreciable growth may be observed, which indicates the termination of the true hibernation period. A growing

period, varying from one to six weeks, ensues, and after this the first molt occurs. In the course of from two to six weeks after the first molt three additional molts take place, and at the conclusion of the fourth molt the phylloxera is mature. This spring growth and development, as observed in the vineyard and in cages, is extended over a period of about three and a half months, and usually occurs during the period from February 15 to April 15. The commencement of growth in phylloxera is noted to be coincident with the first movement of sap in the vine, and naturally both are influenced by prevailing meteorological conditions. Upon reaching the adult stage the hibernant immediately begins the deposition of its eggs, and in this manner the series of parthenogenetic generations destined to continue through the season is commenced.

Measurements.—During the winter of 1913-14 hibernated larvæ were measured at certain intervals to determine at what time the spring growth started. On October 27, 1913, seven individuals which had recently hibernated averaged 0.333 mm. in length and 0.202 mm. in maximum width; on January 6, 1914, four individuals which had hibernated in October, 1913, averaged 0.337 mm. in length and 0.198 mm. in maximum width; on February 23, 1914, four individuals averaged 0.410 mm. in length and 0.217 mm. in maximum width; and on March 10, 1914, five individuals averaged 0.421 mm. and 0.241 mm., respectively. Between October and January there was no difference in size, but between January 6 and February 23 there was a marked difference, both individually and collectively, showing that between these dates the hibernants had begun to feed. The measurements of the individuals taken on March 10 showed that considerable growth occurred between February 23 and that date. None of the insects measured had molted, and observations showed that perceptible growth did not begin before February 10. The average length of the beak of the newly hatched radicle destined to hibernate is slightly over 0.2 mm., but after it has been inserted in the root it becomes somewhat telescoped and measures about 0.17 mm.

The majority of the hibernants before they start to grow are smaller than the newly hatched radicles, and therefore they actually shrink in size after they hatch from the egg and settle to hibernate. Those that feed before hibernating do not shrink to such a small size.

Hibernation in vineyards.—In the vineyards it has been observed that the phylloxerae enter into hibernation as early as September 15 and as late as December 15. Prior to October 1 only a small percentage of hibernants have been found, and after November 20

only a small percentage have been observed that were not hibernants. The greater number of the aphids enter hibernation during October and the first half of November; that is, a majority of the larvæ hatching from eggs in this period settle down to hibernate. A few of those hatching before October become hibernants. After December 1 it is very unusual to find eggs. The phylloxeræ do not enter into hibernation all at one time, and even on a single given grapevine the entering into hibernation is protracted over several weeks and often as long as two months. The causes that induce the young larvæ to hibernate instead of proceeding with their normal growth are three: (1) Condition of sap flow, (2) condition of food, (3) temperature and humidity. Hibernation in general takes place at the time when aerial and radical growth of the vine slacken in the fall. If the soil temperature is high, there is a tendency to postpone hibernating until some time after the terminal growths have apparently ceased. On decayed and decaying roots the phylloxeræ hibernate earlier and on nodosities and sound tuberosities later than on the surface of a normal root. Regarding the influence of temperature, Mayet (15), in discussing the hibernant form, states that eggs die when the temperature falls below 10° C. He states further:

This temperature of 10° C. appears to be the minimum under which the insects become numb, and above which they go out of their torpor * * * M. Maurice Girard proved, experimentally, by means of a freezing mixture, that the phylloxera would sustain a temperature of -8° and -10° C. without dying.

The present writers' observations in the vineyards show that, broadly speaking, when the temperature drops to a minimum of 66° F. about half the individuals are hibernants, and when the maximum in spring has risen to 58° F. about half the individuals have commenced growing. The phylloxeræ enter hibernation under a considerably higher temperature than that which obtains at the time their spring growth begins.

Character of soil has no direct influence on hibernation, but it may have an indirect influence in so far as it may affect the condition of the roots. The heavier soils hold the moisture longer than those of lighter types, bringing about a more rapid decay of the roots and compelling early hibernation. Cold soils also force the insects into early hibernation.

In the vineyards the bulk of the hibernants occur on the lower part of the stump and on the basal portions of the main roots. Hibernants also ascend older vines several inches above the soil surface, where they are concealed under layers of bark. Often most of those that go above the soil surface perish from cold (16). On the smaller rootlets are found small numbers of hibernants, many of them on nodosities on which they pass the winter, frequently with a considerable percentage of mortality. On vines that have been heavily

attacked for years previous, it is unusual to find hibernants, except at the base of large roots or on the trunk, because the roots that were attacked the previous summer tend to rot badly when moistened by winter rains, and consequently most of the hibernants remaining thereon die, and only those higher up on sounder pieces of roots survive in abundance. The basal part of a large root is not generally badly attacked during summer, and so there are not enough tuberosities to rot it during the succeeding winter.

A very noticeable tendency is for the hibernants to congregate in masses. Such masses occur on the normal surface of the root, on tuberosities, on nodosities, and under one or more layers of bark. Perhaps in general on a grossly infested vine more masses occur on the outside bark, but this is only because the preferred sheltered places are too few and are inadequate to cover all the phylloxeræ. On younger vines a favorable location for hibernating is at the foot of the stump. On older vines this position is not so generally chosen. On vines which are only lightly infested the phylloxeræ often congregate at certain spots, while other spots, apparently as favorable, are neglected. On the heavily infested vines all the favorable spots for hibernation are utilized, the majority of the insects being forced to locate on the unsheltered outside bark of the root.

In vineyards the growth and maturing of the hibernants in spring extends over a period about as long as that covered by the entering into hibernation in the fall. The growth first becomes apparent about February 25, and proceeds until the time arrives when the most tardy individuals mature. Immature hibernants are found as late as May, but by April 15 the great majority have become mature. Just as in the case of "entering hibernation," so in the "spring development," a wide range occurs even on single given vines. The earliest individual may commence growth two months or more before the most tardy. On an average, it takes about five weeks for the hibernants to mature after they have first shown perceptible growth. On sound lesions this is shortened to as much as three weeks, and on decaying portions of roots lengthened to as much as eight weeks. Many of those on decayed roots die from ill nourishment before maturing, but the majority of such move away to seek better food.

The forces which influence the growth of the phylloxeræ in spring are a reversal of those which impel hibernation in the fall. As stated, the phylloxeræ start to grow about the time when the sap begins to flow. On dying vines in which the sap flow is either not apparent or very weak, the phylloxeræ on the more healthy roots show perceptible growth in like manner to those living on healthy vines, in which case their activity is supposedly due solely or chiefly to meteorological effect. The spring growth on unhealthy roots

is curtailed and commences late. On nodosities and tuberosities which have remained fresh during winter, the succulent condition of the food induces early growth on the part of the phylloxerae.

Hibernation under cellar conditions.—During the period 1911–1915 hibernation was observed on severed roots in the laboratory cellar. These roots were kept in glass battery jars and in petri dishes and remained in a fresh condition when systematically moistened. Good callus growth and sometimes fleshy offshoots were obtained, especially when a layer of moist sand was placed in the bottom of the dishes. The phylloxerae caused the formation of lesions in similar manner as on roots of living vines.

Under cellar conditions hibernation was often prolonged beyond the period found to occur in the vineyards, and this prolongation resulted in a small number of phylloxerae maturing very late. The “awakening” period in spring was not different from that found in the vineyards under equalized temperatures. Under cellar conditions a greater mortality existed among hibernants than in the vineyards. This was supposedly due to the greater range of daily temperatures, to the abnormal condition of the roots severed from the vine, and to the apparent lack of sap flow. In the cellar hibernants a greater variation in size and color existed, even in unmolted phylloxerae, than in the vineyard on living vines. A very small percentage of hibernants were observed to pass the winter in the second and third instars. Eggs were never observed to pass the winter, since all eggs laid late in the year hatched in due course according to temperatures. No mature or fourth-instar phylloxerae were observed to hibernate. Adult radicicoles in late autumn, as at other times, lived for some days or even weeks after they deposited their last egg, but none was found that survived until spring.

Observations on the hibernation of phylloxerae reared on severed roots under cellar conditions may be summed up as follows: The first phylloxerae entered hibernation as early as August, in extreme cases in July, and the percentage of hibernating individuals from that time gradually increased. By October 1, it was found that on the average about 30 per cent of the individuals were hibernants. By the last of October from 85 to 90 per cent were hibernants. All the living phylloxerae, however, were not hibernants until the end of December, and during November and December a dwindling number of adults and unhatched eggs were observed. All larvae hatching after November 1 settled down to hibernate, and about three-fourths of those which hatched in October did likewise, the individuals comprising the other fourth maturing toward the end of October and in November and continuing to deposit eggs up to December.

The spring growth began in the earliest individuals about January 25; by the middle of March nearly all the phylloxerae were growing and about half were mature. Some individuals remained dormant as late as the middle of April, and the most tardy did not mature until the middle of May or even later. On very poor roots many never matured at all. The period of appreciable growth prior to the shedding of the first skin averaged two weeks and the period from first molt to maturity about three weeks. On vigorous roots the hibernants mostly developed without changing their positions, but they forsook in large numbers roots decayed or decaying. These emigrations occur both before and after molting but chiefly just following a molt.

In comparing the hibernation on severed roots as observed under cellar conditions with that on living roots as observed in the vineyards, in pots, and in special box cages, several points are to be noted. (1) The phylloxerae on the severed roots in the cellar entered hibernation in a more irregular manner than did those on the living vines. This condition appears due to the following causes: The severed roots were cut off from a normal flow of sap, the temperature fluctuations in the cellar were greater, and in the months of July, August, and September the temperature reached a lower daily minimum than in the vineyards; (2) the phylloxerae hibernating in the cellar matured earlier in the spring than those on living vines out of doors by reason of the higher temperature obtaining in the cellar during January and February; (3) there was a greater mortality among the hibernants in the cellar, due to the fact that the severed roots often dried up or decayed before spring; (4) numbers of the phylloxerae occasionally hibernated after they had shown appreciable growth or even cast a skin. This phenomenon rarely has been observed on living roots. In other respects the behavior of the phylloxerae on severed roots did not differ from that on living roots. In exceptional cases vigorous pieces of severed roots were observed to send out fleshy rootlets in early spring, indicating a modified sap flow, and on such roots the phylloxerae moved early and appeared to be influenced by this flow of sap. The comparatively high winter temperatures obtaining in the cellar undoubtedly produced this modified sap flow, since it occurred much earlier than the corresponding flow in the vineyards.

Hibernation on vinifera vines in cages, 1913-14.—The following observations were conducted upon the roots of living vines of different varieties growing in special cages (Pls. V-VII, p. 52). The vines were young and satisfactory specimens for the experiments. The exposed portions of the roots between the upper and lower pots were about 4 inches long, one-fourth inch in diameter, and from 10 to 14 inches below the soil surface of the upper pot. Although both ends

of the exposed portions of roots were surrounded by an inch of fine sand, and all inoculations were made on these exposed portions, it frequently happened that phylloxerae found their way to the unexposed portions, so that in the winter following the inoculations hibernants were found in both the exposed and unexposed portions.

The temperatures in the cages differed but slightly from those recorded simultaneously 2 feet below the soil surface in the laboratory vineyard. In 1913-14 in midwinter, however, the former touched a mark about 10° F. lower, besides being uniformly lower throughout December and January in both the seasons 1913-14 and 1914-15. During the period (August to November) in which the phylloxerae entered hibernation there was no appreciable difference, and before the commencement of the spring growth of the hibernants the temperatures were again equalized. Thus, in the periods of entering into and awakening from hibernation, vineyard conditions were reproduced in the cages as far as temperature was concerned. Contemporaneous vineyard observations show that the behavior of the hibernants on living vines in the cages simulated closely the behavior of those in the vineyards in the locality, and the habit of clustering was often noted. The aphids entered into hibernation and showed spring activity much as they did in the vineyards, but in each phenomenon there was an exception. In 1914, six aphids out of a lot of nine individuals hatching between August 24 and 26 proceeded to hibernate. Such early hibernation with succulent food present is quite unusual in the field. Again, in 1914, on another vine, part of a series of hibernants cast their skins as early as February 23, indicating that growth commenced not later than February 15. In the vineyard, even upon warm soils, the first date of activity was never earlier than February 25. This early spring activity in the cages was possibly due to comparatively high temperatures in February, this being the only month during which the cage temperatures exceeded those in the soil.

Hibernation on American resistant and nonresistant vines in cages, 1914-15.—Along with the vinifera vines planted in the special cages for observing the phylloxerae on living roots, a number of American resistant and nonresistant vines were used for similar observation. The nonresistant varieties (propagated from *Vitis labrusca* and *V. aestivalis*) were Catawba, Isabella, Lenoir, Delaware, and Champion. The Muscadine (*V. rotundifolia*) was used also. The resistant hybrids, some of which were grafted to viniferae, comprised Mourvedre × Rupestris 1202, Solonis × Riparia 1616, Berlandieri × Riparia 157.11, Riparia × Rupestris × Aestivalis × Monticola 554.5, Aramon Rupestris Ganzin 1, Riparia Gloire de Montpellier, Rupestris St. George. These vines were planted in the spring of 1914 and inoculated thereafter.

On the Muscadine the phylloxerae upon hatching from the eggs refused to settle or feed. The nonresistant varieties were infested throughout summer and autumn, and on their roots the phylloxerae entered into hibernation from September 20 to the beginning of November; in the case of the Champion, they hibernated as late as December 1. On the Catawba and Champion, the most heavily infested, the aphids began hibernation earlier; on the less infested Delaware, Isabella, and Lenoir, somewhat later.

Aphids became active about the middle of February, and all hibernants were adult by April 13. This spring activity was somewhat in advance of that occurring in vineyards, but was similar to that which occurred on the caged vinifera vines. On all nonresistant varieties it was observed that the hibernants massed on tuberosities, nodosities, and the normal surface of the roots; and in cracks in a manner similar to that observed to occur on vinifera vines.

On the resistant hybrids repeated inoculations during summer and autumn failed to produce more than an extremely light infestation. The phylloxerae settled to hibernate during October, and at the end of that month all were hibernants. They were situated on side rootlets and on the normal surface of the root, but on the Rupestris St. George hibernants occurred also on nodosities which they had caused to form shortly after they settled.

Hibernation on American vines in pots, 1912-1915.—A large series of 2-year-old vines (from cuttings) planted in 6-inch pots, originally used in resistance experiments and comprising resistant vines, were examined during the years 1912 and 1913 for hibernant observations. It was found that hibernation took place during the last half of October and first half of November and that the spring awakening proceeded from about March 10 to April 15. These vines were planted in light sandy soil. The hibernants settled chiefly on nodosities and to a smaller extent on the surface of the larger rootlets. In the spring there was a great variation in the growth of the vines. In the majority of instances the phylloxerae on the early leafing vines molted sooner than those on the more backward plants. No temperature records were kept with this series, but it is probable that the records taken 2 feet below the soil surface (Table XII) approximated that which occurred in the pots in the winter of 1913-14.

A further series (1914) of rooted vines in 9-inch pots, comprising Agawam, Isabella, Lenoir, Delaware, Catawba, and Champion, showed that with the exception of the Delaware, which was lightly infested, hibernation proceeded from about October 1 to November 1, nearly all the insects being hibernants on the latter date. On the Delaware none of the phylloxerae were hibernants on October 30, and the roots were on that date still running strongly in sap, while the sap flow in the other varieties was weaker. The temperature in

these pots was about the same as that occurring 2 feet below the soil surface. In the spring of 1915, on the Champion, Lenoir, Catawba, and Isabella, the phylloxera began to grow about March 1. On the first three the bulk of the hibernants were mature April 6, but on the Isabella, which was moribund, more than half were unmolted. This vine was not retained further, but, considering the condition of its roots, it is not probable that any of the phylloxera would have matured. The vine was too weak to send out new rootlets, and the roots showed much decay. The abundance of phylloxera the summer previous had doubtless caused this weakness.

THE RADICICOLE.

EGG DEPOSITION.

The adult radicle commences to deposit eggs within 48 hours after the final molt. Occasionally there occur abnormal individuals which delay deposition of eggs as much as two weeks, and again there are others which fail to deposit eggs but continue alive for some weeks.

Egg deposition on severed roots.—Table III gives the summarized record of the egg deposition of radicles under cellar conditions during the years 1911–12.

TABLE III.—*Summarized record of egg deposition of radicles of the grape phylloxera under cellar conditions during 1911–12, Walnut Creek, Calif.*

Generation.	Number of adults.	Egg-laying period for generation.	Number of eggs per adult.			Days in period of deposition.			Average number of eggs per adult per day.
			Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	
1 ⁰	52	Apr. 21 to Oct. 1.....	347	4	84.6	110	2	55.3	1.53
1	45	May 27 to Sept. 23.....	486	10	192.0	96	5	46.3	4.1
2	57	June 29 to Nov. 6.....	287	2	102.0	106	1	48.5	2.1
3	17	Aug. 4 to Dec. 7.....	266	3	141.8	96	2	44	3.2
4	² 11	Sept. 5 to May 15, 1912.....	119	31	67.2	83	23	41.7	1.6
³ 5–10	27	Apr. 26 to Oct. 6.....	137	4	35.5	47	3	21.5	1.7

¹ Overwintered generation. ² Including 3 individuals which matured in 1912. ³ Throughout 1912.

Neglecting the series of generations 5 to 10, the individuals of which suffered through abnormal food and other conditions, it is shown in Table III that the aphids of the second generation were the most prolific. One aphid deposited 486 eggs in 79 days, an average of 6.3 per diem. The greatest number of eggs laid within 24 hours by a single adult was 23 and the longest laying period covered 110 days. A true seasonal average of the number of eggs deposited by each aphid was 117 for 1911 and a similar average of the number of eggs per diem per aphid about 2½.

In 1913, between June 26 and November 14, a series of observations on fecundity under adverse food conditions was made. Among a large number of aphids, on two occasions only were as many as six eggs deposited in one day by a single individual. In the cellar, 431 eggs were deposited in a total of 331 days (1.3 eggs per diem per aphid), and in an electric incubator, wherein a slightly higher temperature was maintained, 787 eggs were laid in a total of 463 days (1.7 eggs per diem per aphid). These averages were considerably less than corresponding ones found to result in the 1911 series, yet the insects raised in the incubator were subjected to higher temperatures than were those in 1911, raised in the cellar.

Egg deposition on living vines.—During the years 1913, 1914, and 1915, series of generations were raised on living vines in cages. These vines were all viniferæ, and comprised the following varieties: Muscat, Zinfandel, Mission, Burger, Thompson's Seedless, and Grenache. The principal object in this work was to check up on the previous 2-year study of root cuttings under cellar conditions. The initial inoculations in 1913 were made with eggs laid by adults of the overwintered generation on Zinfandel vines in the vineyard, and thus no record of the egg production of the overwintered adults was secured in the cages. Of the first generation, records of 10 individuals were taken, but a complete record of only one was made, and this adult, between June 25 and July 14 (20 days), deposited 121 eggs, the largest number in a single day being 12. The 10 adults deposited 482 eggs in 95 days, or an average of 3.1 eggs per diem per adult.

Most of the individuals died early, and it is assumed that if they had been allowed to lay their full complement of eggs, the period of decline would have reduced this average. These adults were produced, 7 on Burger roots and 3 on Mission roots. It appeared that those on the Mission were the more prolific. On both varieties some were situated on lesions they had caused to form. These averaged better in egg production than the others situated on the normal root surface. Records for 14 adults of the second generation were taken. On a very healthy Mission root, living on lesions, 4 adults averaged 4.5 eggs per adult per diem. On two less healthy Mission roots of the same cage vine, 6 averaged 2.4 eggs per adult per diem. On a very healthy Burger root 4 averaged 3.9. The longest egg-laying period for any adult of this generation was 26 days and the maximum eggs per day 15. In all, 489 eggs were laid in 136 days, 3.6 eggs per adult per diem.

The egg-laying period of this generation ran from July 8 to August 15, with an average temperature of 68° F. Four adults of the third generation deposited 284 eggs in 88 days, at an average of 3.2 eggs per diem per adult; the longest egg-laying period was 28 days and the maximum number of eggs per diem was 8. These

adults lived on a healthy Muscat root on tuberosities, their egg-laying period being from August 28 to September 26, under an average temperature of 64° F. One of them did not commence depositing eggs until the sixth day after it matured, having moved about considerably meanwhile. The fourth-generation phylloxeræ wintered on the same root upon which their immediate progenitors had oviposited and matured in the spring of 1914. Of these, 3 adults laid 79 eggs in 42 days (aggregated) or 1.9 eggs per diem per adult. The maximum number for one day for a single adult was 4 and the longest egg-laying period 24 days. In this period one adult laid 56 eggs. The egg-laying period, toward the end of which the root became lightly decayed, ran from April 6 to May 8, under a temperature averaging 58° F.

In the ensuing generations throughout 1914 and 1915, the egg-laying records were mostly incomplete. Records of the fifth generation on Muscat in the period May 28 to June 11 show an average number of eggs per diem per adult to be 2.8, the largest number deposited in a single day by a single adult being 5. The average temperature was 65° F. Records of the seventh generation on a slightly decayed Grenache root, July 29 to August 8, show an average number of eggs per diem per adult to be 5.4, and the maximum number of eggs laid in a single day to be 7. The temperature averaged 71° F. The records of these two lots are much too meager for comparisons.

In comparing the egg production on the living vines with that on root cuttings, it should be stated that during the summer and fall months the aphids on the former enjoyed higher temperatures. This advantage was somewhat counterbalanced by the greater daily fluctuations in temperature which took place on caged living vines and which frequently resulted in a daily minimum lower than that simultaneously occurring in the laboratory cellar in which the root cuttings were kept.

As a general rule the egg-depositing capacity of the adult increases rapidly after maturity, and after the zenith is reached decreases slowly, so that half the complement of eggs is deposited before one-third of the egg-laying period is completed.

The condition of the food is the chief factor in the production of eggs, but there is also a meteorological control. Frequent fluctuations in temperature and humidity adversely affect deposition.

Extrusion of the egg.—During the process of egg extrusion, which occupies from 20 to 40 minutes, the abdomen of the adult radicle is considerably distended. It is apparent, therefore, that when an adult deposits 23 eggs within one day, extrusion will be taking place intermittently for a very considerable part of the day. During the

period of egg deposition, the aphids often change their orientation by pivoting about the beak.

Time of day of oviposition.—Between April 28 and May 25, 1913, records were taken in the cellar to obtain data upon the time of day of oviposition. The maximum daily temperature occurred about 6 p. m.,⁹ and the minimum about 7.30 a. m. Between 9 a. m. and 5 p. m. (8 hours), 41 eggs were deposited, and between 5 p. m. and 9 a. m. (16 hours), 52 eggs were deposited in the 27 days. Between 9 a. m. and 5 p. m., there was an average hourly temperature in excess of that occurring between 5 p. m. and 9 a. m. of about 0.02° F. It is apparent that the higher temperature of the shorter period caused a comparatively greater number of eggs to be deposited, since the 52 eggs were laid in exactly double the time in which the 41 were deposited.

Egg fertility and mortality.—A large series of experiments took place in 1911 to determine the fertility and mortality percentages of the eggs of the radicle phylloxera. These were carried on about evenly throughout the year. One series was conducted under cellar conditions in petri dishes, and the other took place in the laboratory under a higher temperature and was exposed to subdued daylight. Table IV gives the results of these experiments:

TABLE IV.—*Fertility and mortality of the radicle egg of the grape phylloxera, Walnut Creek, Calif., 1911.*

Generation and environment.	Total number of eggs deposited.	Number of eggs hatched.	Number of eggs that failed to hatch.	Percentage hatched.
Unknown (various).....	965	772	193	80.00
1 (Cellar).....	1,000	911	89	91.10
1 (Exposed to light).....	490	422	68	86.12
1 (Total).....	1,490	1,333	157	89.52
2 (Cellar).....	1,840	1,716	124	93.26
2 (Exposed to light).....	245	236	9	96.33
2 (Total).....	2,085	1,952	133	93.62
3 (Cellar).....	1,112	987	125	88.76
4 (Exposed to light).....	524	486	38	92.75
Grand total.....	6,176	5,530	646	89.54

There was no appreciable difference between the fertility of those reared in the cellar and of those reared in the higher temperatures of the laboratory rooms. The results indicate that on the average almost 9 eggs out of every 10 laid will hatch. It is probable that vineyard conditions produced similar averages as no predators or other causes that might bring about a different average have been observed with the exception of the case of excessive spring moisture acting upon the eggs laid by the overwintered adults and in the case

⁹ All references to clock time refer to "Standard time."

of eggs laid on rotting tuberosities. The eggs have a considerable resistance to water at ordinary temperatures and may also hatch under water. Many, probably 25 per cent, of those that are laid on rotting tuberosities fail to hatch. They seem to be so impregnated with dampness and influenced by the rotting root tissues surrounding them that they turn dark brown prematurely and finally collapse after the embryo dies. It must be considered also that very slight pressure applied to the eggshell may rupture it and kill the embryo.

INCUBATION PERIOD.

The first incubation record at Walnut Creek took place during April, 1909. Between April 9 and April 26, 24 eggs were observed in the laboratory with the results shown in Table V:

TABLE V.—*Incubation period of the eggs of the grape phylloxera, Walnut Creek, Calif., 1909.*

	Days.
Average incubation stage.....	13.8
Maximum incubation stage.....	15
Minimum incubation stage.....	12

No temperature records were taken. The eggs were presumably deposited by overwintered adults. During 1911 and 1912 a large series of incubation records was obtained. Table VI gives incubation records for each generation during 1911.

TABLE VI.—*Incubation records of the eggs of the grape phylloxera at Walnut Creek, Calif., 1911.*

Generation.	Environment.	Dates of period of incubation.	Average temperature.	Number of eggs laid.	Incubation period.		
					Maximum.	Minimum.	Average.
					<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
¹ I	Cellar.....	Apr. 28–May 18....	61	49	17	10	13.6
² I	do.....	June 4–Aug. 19....	64	889	15	8	10.8
² I	Laboratory shelf...	June 13–Sept. 6....	(³)	412	13	7	9.8
II	Cellar.....	June 13–Aug. 19....	64.5	1,797	14	7	10.2
II	Laboratory shelf...	June 5–Aug. 18....	(³)	235	11	6	8.5
III	Cellar.....	July 7–Aug. 20....	64.6	999	14	7	11.7
IV	Laboratory shelf...	Aug. 9–Sept. 2....	(³)	551	10	6	7.2
IV	Cellar.....	Aug. 18–Oct. 26....	64	10	18	7	13.3

¹ Eggs deposited by overwintered adults.

² Later series of eggs deposited by overwintered adults.

³ Temperature at least 5° higher than that in cellar at corresponding dates.

From Table VI it will be seen that the influence of temperature was very considerable. The records of 1912 are much more scanty and bear out the observations of 1911. Under an average temperature of 70° F. the egg stage in 1912 averaged 8.9 days, with a maximum and minimum of 10 and 7 days, respectively. The period covered was from June 19 to October 3, but the great majority of the total of 55 eggs were laid during June. A small series of 27 sixth-

generation eggs, laid May 6 to 8, 1912, under an average temperature of 63° F., incubated in an average of 10.7 days.

The results shown in Table VII were obtained during 1911 and are in part a complement of those shown in Table VI:

TABLE VII.—*Incubation records of the eggs of the grape phylloxera, Walnut Creek, Calif., 1911.*

Group No.	Environment.	Average temperature.	Month of incubation.	Number of eggs.	Egg stage.		
					Average.	Maximum.	Minimum.
1	Exposed to light.....	° F. 57	April.....	43	15.14	18	13
2	do.....	60	May.....	177	11.03	15	9
3	do.....	65	June.....	352	9.07	12	8
4	do.....	52	November...	16	15.09	18	15
5	In darkness, laboratory drawer...	62	May-June...	323	10.66	14	9

The eggs of the first four groups in the preceding table were exposed to light on a shelf in the laboratory, and those of group 5 were incubated in a drawer in the laboratory. Both lots were subjected to a very abnormal fluctuation of temperature, this fluctuation in some cases reaching 20° F. daily.

In 1912, 1913, and 1915 some additional incubation records were obtained, and Table VIII indicates the relations between temperature, environment, and incubation to cover the four years, 1911, 1912, 1913, and 1915.

TABLE VIII.—*Relation between incubation, temperature, and environment in the egg deposition of the grape phylloxera, Walnut Creek, Calif., 1911-1913 and 1915.*

Lot No.	Year.	Number of eggs.	Average daily temperature.	Incubation.	Remarks on environment.
			° F.	Days.	
1	1911.....	16	52	15.09	Exposed to light.
2	1915.....	13	55	20.50	Cellar.
3	1913.....	26	56.6	¹ 19.60	Do.
4	1911.....	43	57	15.14	Exposed to light.
5	1915.....	17	59	15.50	Cellar.
6	1911.....	177	60	11.03	Exposed to light.
7	1915.....	16	60.5	15.40	Cellar.
8	1911.....	49	61	13.60	Do.
9	1913.....	38	61.3	15.50	Do.
10	1912.....	26	63	10.70	Do.
11	1913.....	48	63	15.50	Do.
12	1915.....	28	63.8	11.00	Do.
13	1911.....	889	64	10.80	Do.
14	1911.....	10	64	13.30	Do.
15	1911.....	1,797	64.5	10.20	Do.
16	1911.....	969	64.6	11.70	Do.
17	1911.....	286	65	10.29	Laboratory drawer—darkness.
18	1911.....	352	65	9.07	Exposed to light.
19	1915.....	13	65	9.40	Cellar.
20	1913.....	20	67	9.65	Do.
21	1915.....	22	67.3	8.80	Do.
22	1913.....	22	68	9.00	Do.
23	1915.....	62	68	² 7.00	Do.
24	1915.....	21	68.5	7.60	Do.
25	1912.....	55	70	8.90	Incubator.
26	1913.....	61	70.3	8.40	Do.
27	1913.....	38	72	8.70	Do.

¹ Maximum, 27 days.

² Minimum, 5 days.

Examination of Table VIII shows that the incubation period gradually becomes shorter as the temperature rises.

The exposure to light apparently produced abnormal rapidity in the development of the eggs. In lot 18 this influence was scarcely felt, while in lots 1, 4, and 6 it was very cogent, and it is evident that exposure to light is chiefly influential under low temperatures. The comparatively slow development of lots 25 to 27 apparently can be laid only to temperature fluctuations obtaining in the incubator. This fluctuation in the incubator sometimes consisted in the maintenance of a lower minimum for a longer period than that which obtained in the main part of the cellar. Such temperatures possibly would exert a retarding effect upon egg development that would not appear in the averaged readings of the thermometer.

Even among the lots kept in the cellar under similar conditions there were apparent exceptions to the rule that "the higher the temperature the shorter the period of incubation." One such instance is that of lots 15 and 16, in which two large series were used, yet under temperatures differing but 0.1° F. there was a difference in the average incubation periods of one and a half days.

Among the individuals enumerated in Table VIII the maximum egg stage was 27 and the minimum 5 days. The respective average temperatures influencing the two individuals were 55° F. and 68° F., and both were incubated in the cellar. It was possible only to estimate an annual average incubation stage, and this was about 11 days. It should be added that eggs have been observed in December to incubate in a period exceeding 30 days, but it is unusual to find eggs at this time of year.

Experiments conducted in the cellar demonstrated that eggs incubated as rapidly in arid as in humid surroundings, but submergence in water lengthened the incubation period, even under equal temperatures.

Incubation on living roots.—During the years 1913, 1914, and 1915 biologic records were made on the living roots of young vines of *vinifera* and *vinifera* $\times$ American hybrids. A series of generations were conducted during these three years, and incubation was observed for each generation. In most cases immediately after deposition the eggs were removed to an unfested root, but in some they were allowed to incubate where they had been deposited. The cages containing the experimental vines were all placed together in one trench, and the temperature was alike in all of them. Table IX indicates the incubation periods with reference to temperatures and time of year. The years are not given, as in some instances

single lots containing individuals incubating under the same average temperatures but belonging to more than one year have been combined.

TABLE IX.—*Incubation of the eggs of the grape phylloxera on living roots, Walnut Creek, Calif., 1913-1915.*

Lot number.	Number of eggs.	Average temperature.	Incubation.	Months or month.
		^o F.	Days.	
1.....	19	56.8	[†] 19.0	March to April.
2.....	11	57	15.1	April.
3.....	11	58	14.8	April to May.
4.....	(²)	58.5	15.0	Do.
5.....	7	60	12.3	Do.
6.....	6	61.8	11.2	May to June.
7.....	(²)	62	9.0	Do.
8.....	28	63	9.0	Do.
9.....	(²)	64	9.7	June.
10.....	3	66	³ 9.5	Do.
11.....	11	68	10.5	September to October.
12.....	23	69	³ 8.2	June to October.
13.....	26	70.5	³ 7.7	June to September.
14.....	21	71.5	9.4	Do.
15.....	11	72	8.4	August.
16.....	45	72.5	³ 7.7	July to September.
17.....	23	73	³ 7.0	Do.
18.....	8	73.2	³ 6.4	July.

¹ Maximum, 20 days.

² About 20.

³ Minimum, 6 days.

Many of the lots contained a very small number of individuals, but in the main the incubation stage became progressively shorter as the average temperature rose. Between the temperatures of 56.8° and 62° F. the incubation periods are rapidly reduced, while between 62° and 73.2° the reduction is much less rapid in proportion to the rise in temperature. This is a somewhat similar condition to that found in the cellar records.

It is evident that the stage was shortest during the months of July and August, and longest during the months of March and April. Records began as early in the year as March 31, and closed as late as October 5. Two of the individuals in lot 1 incubated in the maximum period of 20 days (Mar. 31 to Apr. 20) under an average temperature daily of 56.8° F. The minimum of six days was reached by 17 individuals in each of the months from June to September under average daily temperatures of from 66° to 73.2° F.

The condition of food had no apparent effect upon the duration of the egg stage. Eggs deposited by radicles which had developed from eggs deposited by gallicoles received from Virginia incubated in the same average period as those descended from radicles of many generations, and eggs deposited by nymphicals incubated precisely as did those laid by normal radicles. Individual incubation records, both of eggs reared in the laboratory cellar and of others reared on living vines, are given in connection with the development of the radicles under the same conditions in the section on "Development of the radicle larva," pages 54, 55, 57, 60-62, and 63.

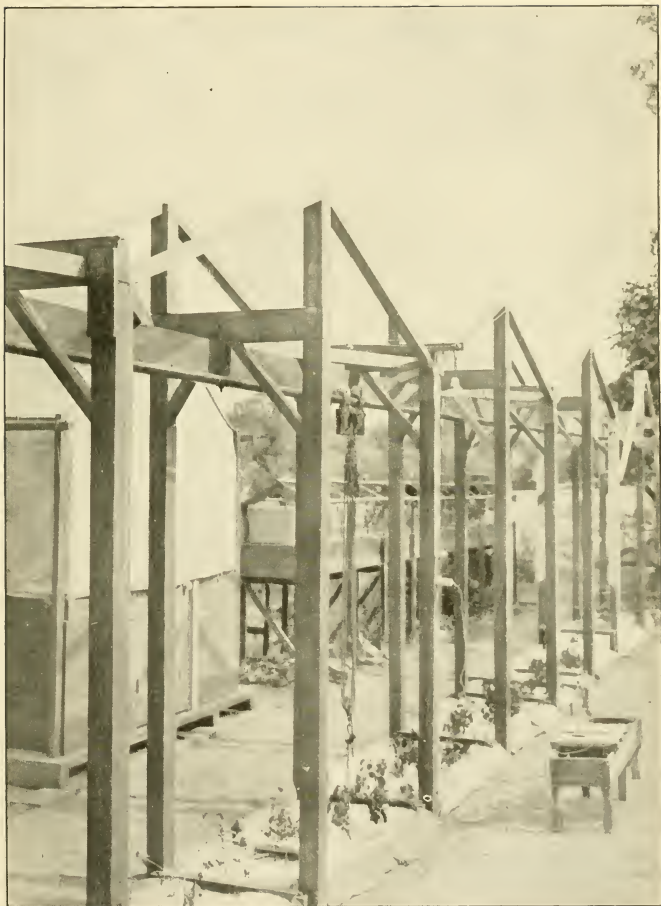
METHODS OF REARING THE RADICICOLE LARVÆ.

During 1911 and 1912 the radicicoles were reared exclusively, both within and without an electric incubator, in the cellar. The roots on which the phylloxeræ were reared were kept in glass jars and in petri dishes with moistened filter paper. This method was not always satisfactory, since it was not easy to maintain an even humidity similar to that existing under natural conditions.

In 1913, 1914, and 1915 the insects were reared in the cellar and in the cages described below. The jars in the cellar were moistened by a layer of wet sand placed in the bottom. This method was more successful than in the case where moistened paper was utilized; the roots did not decay or dry up so rapidly, and they remained in much better condition through the winter.

These cages (Pls. V; VI, fig. 1; VII), constructed to hold young vines, may be described as follows: A trench 3 feet deep was dug wide enough to hold the cages with a space about 1 inch wide on each side. To prevent air passing down the cracks, small blankets were laid across the spaces, and this resulted in a temperature inside the cages of scarcely greater fluctuation than normally occurred 2 feet underground. The cages themselves were made of paraffined pine with an extra redwood bottom, and had two compartments, one above the other (Pl. VII). The upper compartment had on each side one, and the lower two, detachable boards the whole length of the major sides, and these boards were detachable to permit examination of the roots and the removal of the pots. The upper compartment contained one and sometimes two pots (8 or 9 inches in diameter), around the top of which was fitted the topmost board of the cage, the outside measurements of which were 22 by 13 by 27 inches. The lower compartment contained 9-inch pots in saucers.

The method of planting the vines in the pots of the cages was as follows: Into the middle board of the cages were fastened one or two saucers having holes bored through them. A short piece of glass tubing larger inside than the diameter of the roots was fixed into these holes with a cone of paraffin. Two half pots, bottomless, were bound together by wire or tin bands to make a single whole pot, and placed to rest on the saucer. The vine was then put in place, certain of its roots being passed through the holes in the saucer and protruding below. The upper pot was then filled with soil with a thin top layer of fine sand. In the lower compartment, whole 9-inch pots, one or two, as the case might be, were put in place in their saucers, and the protruding roots planted in them, at the surface of the soil passing through about 3 inches of glass cylinder. The surface of the soil in the lower pots was covered in most cases with a thin layer of fine sand. Fine sand was tamped into the glass cylinders,



THE GRAPE PHYLLOXERA IN CALIFORNIA.

General view of pit and rearing boxes employed in life-history studies of the grape Phylloxera.

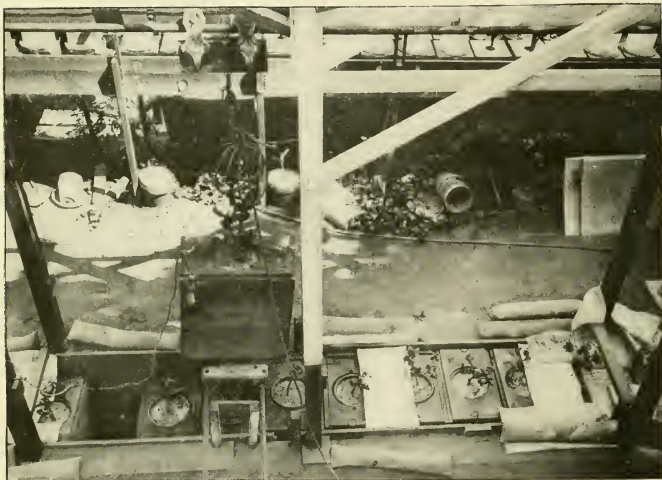


FIG. 1.—Pit with rearing boxes, illustrating method of covering with quilted strips to preserve same temperature as in like depth of soil.

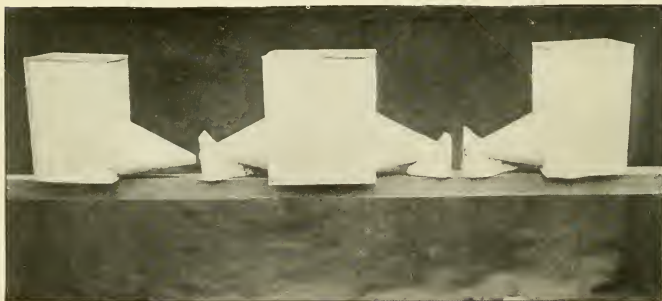
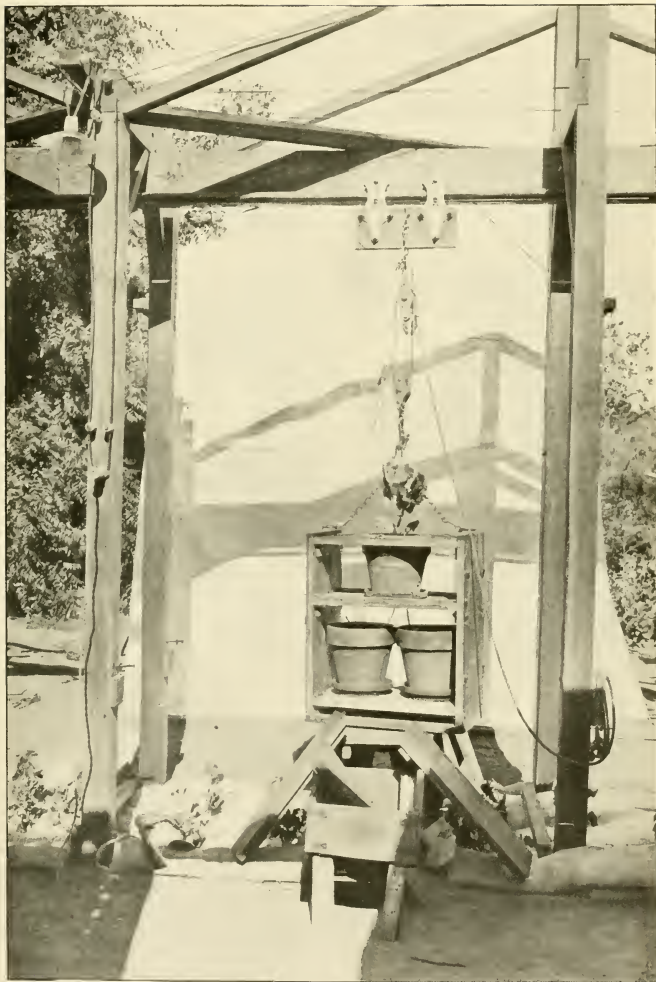


FIG. 2.—Galvanized tin cans used in connection with studies of the underground diffusion of Phylloxera.

THE GRAPE PHYLLOXERA IN CALIFORNIA.



THE GRAPE PHYLLOXERA IN CALIFORNIA.

Rearing box drawn up from pit; sides of box removed.

and those in the saucers above were also plugged with cotton. This procedure tended to prevent the phylloxerae from leaving the exposed portion of the root between the saucer of the upper pot and the surface of the lower. This exposed portion of living root averaged about 4 inches in length.

Scaffolding was built above the trench and a rope and pulleys provided in order that the cages might be raised and set in place on the stand for examination of roots. Electric connections were also provided so as to enable the cages to be examined after dark.

The cages above described were designed by R. L. Nougaret.

DEVELOPMENT OF THE RADICICOLE LARVA.

The young radicle larva (Pl. IX, *g*, *h*, p. 64), upon hatching from the egg, seeks a place on the root where it may implant its beak and settle down to feed. During the summer some of the newly hatched larvæ desert the vine and go in search of other vines, traveling either through cracks in the soil or over its surface. Newly hatched larvæ are very active at all times and, being flat, can go through very small passages. Considering only those that remain on the vine on which they were born, it is found that the length of time elapsing between the hatching and settling on the root surface varies according to conditions of food at hand. On a decaying root the insect may not find a location for several hours, but if the root is sound the larvæ mostly settle down immediately close by the eggshells.

A certain percentage of larvæ always wanders about on the roots before finally settling. Many of these make their way outward and downward to the smaller rootlets, while others (mostly of the hibernant generation) in the fall make their way up to the bases of the larger roots and even to the main trunk. Larvæ hatching on a decayed root usually leave it, but occasionally they remain and die of starvation. Observations on pieces of severed roots kept under cellar conditions indicated very little movement of the young larvæ, provided their food was in good condition and they were not too much crowded. In the summer, however, large numbers deserted the roots in a manner similar to that observed in the vineyards, and these were apparently imbued with a wandering instinct.

On vinifera vines young larvæ prefer to settle on succulent parts of roots or rootlets. When they settle on growing rootlets, they generally cause the formation of nodosities, and on the roots of one or more year's growth the formation of tuberosities. They frequently settle on lesions already formed by older phylloxerae, and sometimes they settle and mature on the root without causing any perceptible lesion. When no lesion is formed, the insects develop

slowly, and as a rule the larger and more fleshy the lesion the more rapid is the growth of the insect thereon. On resistant vines the newly hatched larva rarely fastens on any place except the apex of the rootlet or on a nodosity already formed. On American non-resistant vines the larvæ settle in the main as they do on viniferae, but on some varieties a decided preference is given to the growing rootlets over the larger roots.

During the years 1911 and 1912 experiments were conducted to determine the growth and development of radicles under cellar conditions. Table X summarizes these observations.

TABLE X.—*Summarized records of incubation and development of the radicle of the grape phylloxera under cellar conditions, during 1911 and 1912, Walnut Creek, Calif.*

Generation.	Number of individuals.	Incubation period.			Number of individuals.	Developmental period.			Number of individuals.	Generation cycle.			Average temperature during period of development.
		Maximum.	Minimum.	Average.		Maximum.	Minimum.	Average.		Maximum.	Minimum.	Average.	
		Days.	Days.	Days.		Days.	Days.	Days.		Days.	Days.	Days.	° F.
1.....	49	17	10	13.6	181	48	13	29.6	49	56	26	40.5	63
2.....	58	13	8	10.2	352	61	16	31.7	58	74	25	42.2	64
3.....	21	12	8	10.1	30	41	16	26.6	21	52	26	37.2	64½
4.....	10	18	7	13.3	8	24	17	21.9	8	38	24	34.6	64
4½.....					13	208	125	183.0					
5-9².....	3	12	11	11.3	18	45	14	27.6	3	41	35	37.3	

¹ Hibernating individuals, maturing in 1912.

² In 1912 the records extend from Mar. 20 to July 22.

A summary of the observations made on the growth and development of the radicle on severed root cuttings in the cellar in 1911 and 1912 may be given in brief. The great variation existing in the growth of individuals under the same temperatures, and even on a given piece of root, is resultant entirely from the condition of the food. An aphid living on a callus formation or tuberous lesion develops more rapidly than one living on the normal surface of the same piece of root. Individuals living on vigorous roots develop more rapidly than those on decayed or dying roots. Occasionally a decaying root will send out very fleshy lesions, and these, while they remain fresh, provide ample nourishment for the aphids and enable them to grow quickly. After a root reaches a certain point in decay or dryness the phylloxerae can no longer develop on it and must seek better food or perish.

The growing period of the aphids recorded in Table X ranged from 13 to 61 days, hibernating individuals excluded. The grand average, hibernants not considered, was 30.57 days, practically one month. That the maximum period may be prolonged is evidenced from an observation made in the summer of 1912, in which a series

of individuals lived from 90 to 105 days on a particularly innutritious piece of root without maturing.

During 1913 two series of further experiments were undertaken. One series was reared in the cellar and the other in an electric incubator, the latter under somewhat higher temperatures. Generations were followed from May to October. Table XI summarizes these observations.

TABLE XI.—*Development of radicles of the grape phylloxera, Walnut Creek, Calif., 1913.*

Environment.	Generation.	Number of individuals.	Average period of growth.	Average temperature.
				° F.
Cellar.....	1	44	37.25	65.1
Do.....	2	10	32.40	69.8
Incubator.....	1	15	35.60	65.6
Do.....	2	24	28.80	71.1
Do.....	3	3	29.70	70.3

From this table it is noticeable that temperature exerted considerable influence on the growing period of the aphids, and that warmth accelerated their development. In a series of generations reared in 1915 on very nutritious food, recorded under the heading "Maximum and minimum generations yearly" (p. 71), this temperature influence is very apparent. The greater constant warmth in the incubator induced the aphids to remain active later in the fall, after those in the cellar had hibernated. In comparing the 1913 series with those of 1911, it was found that the aphids of the former developed more slowly than did those of the latter, and this notwithstanding the fact that both the series of 1913 enjoyed higher temperatures than did the cellar series of 1911. The roots supplied in 1913 were of much poorer quality than were those supplied in 1911.

Development on living roots, 1913-1915.—During 1913, 1914, and 1915 the habits and development of the radicles were observed on living roots of vines growing in cages (Pls. V; VI, fig. 1; VII) kept in a trench where the temperature approximated that obtaining beneath the surface of the soil. As far as the temperature was concerned, the monthly averages ranged less than did those obtaining about 2 feet below the soil surface, but the daily fluctuations were considerably in excess of those in the soil. In the cages the roots were subjected to an average daily fluctuation of about 3° F. in summer and about 2° F. in winter. Two feet beneath the surface, the temperature never fluctuated more than 1° in any given day. As far as could be observed, this temperature fluctuation had little effect on the growth of phylloxera, except that it seemed to cause the nodosities to decay more rapidly than they would normally. Occasionally it was noted that some nodosities would dry up quickly after the cage had

been examined and its interior subjected for a few minutes to a temperature several degrees in excess of that obtaining in the trench immediately preceding the examination.

Plate VII illustrates the details of the cages used for observing the phylloxeræ on living roots. By means of the pulley and stand the cages were hauled up and set for examination. It is obvious that only young vines could be used for this work, as 9-inch pots were the largest used. The vines were planted in early spring, certain of the longer roots, drawn through holes cut in the saucer supporting the bottomless upper pot, being planted in the lower pots. Thus about 4 inches of root between upper and lower pots were available for inoculation and observation. At the upper and lower ends of this visible portion the root passed through glass cylinders, and the intervening spaces between the root and cylinder were filled with sand and cotton (sand only was used in the lower cylinders) to prevent the escape of phylloxeræ to the invisible portions of the roots, both above and below. For the viniferæ and nonresistant American vines this, however, failed to answer the purpose in many cases. Out of 22 upper pots, which were examined several months after the exposed roots were inoculated and had suffered more or less severe infestation, 18 developed infestation on their roots, showing that phylloxeræ had found their way up to the roots in the upper pots. Out of 36 lower pots liable to infestation on their roots by reason of the fact that the exposed portions of the roots above were infested, the roots in 9 showed no infestation or indications of any previous infestation, whereas in 13 others infestation occurred which had resulted from larvæ successfully penetrating the lower glass cylinders; in the remaining 14 pots, infestation or signs of previous infestation occurred resulting from wanderers reaching the rootlets by penetrating cracks in the soil. In the case of the resistants, the cylinders of sand and cotton packed between roots and glass were effectual in preventing spread to the invisible portions of the roots. On these vines the infestation was always very slight, and the phylloxeræ exhibited very little desire to travel. On a Champini (rupestris $\times$ candicans), on which the phylloxeræ infested only the side rootlets, and which bore only a slight infestation, wandering larvæ entered the soil and infested the rootlets of one of the lower pots, but there was no penetration through the glass cylinders.

As temperature is a factor of importance in the development of the phylloxera, the following comparisons (Table XII) of temperatures are noteworthy, taken (1) inside the cages containing living vines, (2) 2 feet below the soil surface, at a point in the laboratory vineyard a few feet distant from the trench containing the cages aforesaid, and (3) in the laboratory cellar:

TABLE XII.—*Comparative monthly average temperatures; inside cages in trench, 2 feet below soil surface in laboratory vineyard, and in laboratory cellar, Walnut Creek, Calif.*

Month.	Two feet below surface.	In cages in trench.	In laboratory cellar.
1913.	° F.	° F.	° F.
May.....		59	
June.....		68	
July.....	76	71	
August.....	77	71	
September.....	77	69	68
October.....	70.5	65	63
November.....	64	56	59
December.....	53	49	56
1914.			
January.....	54	52	55
February.....	51	52	55
March.....	58	56	58
April.....	62	58	59
May.....	65.5	63	62
June.....	70	68	65
July.....	72.5	72	67
August.....	74	72	69
September.....	70.5	66	67
October.....	66	64	63
November.....	58.5	56	58
December.....	50.5		54
1915.			
January.....	49		54
February.....	52		55.5
March.....	57	56.5	57
April.....	62	57	58
May.....	63.5	59	60
June.....	71.5	68	65
July.....	75.5	73	68
August.....	75	73.5	69
September.....	71.5	69	66
October.....	66	64.5	62

¹ Approximate.

Examination of Table XII indicates that the cellar temperatures showed the least annual variation and that the average temperatures in the soil for every month, except February, 1914, exceeded the corresponding temperatures in the cages. It is probable, leaving other factors out of consideration, that the accumulated excess of heat in the soil over that in the cages throughout one season would produce an extra generation of phylloxeræ, besides prolonging the active development later into the autumn. The summer of 1913 was much warmer than that of the year following. This is borne out by the soil temperature comparisons, but does not appear from the cage temperatures.

To obtain life-history data, the following vines were used: Burger, Muscat, Thompson's Seedless, Mission, Champini, and Grenache. On the Champini the phylloxeræ refused to settle, except on fleshy side-rootlets, but on the others they settled at any point. On the Grenache roots, however, several of the inoculations proved unsuccessful, the young larvæ not settling. On the others, inoculations nearly always proved successful. Inoculations were made by transferring eggs from one root to another with a camel's-hair brush. Since the roots in all cases were vertical, or very nearly so, it happened

occasionally that some of the eggs used in the inoculations dropped off. This was unavoidable, and when egg-laying females were under observation it frequently happened that the eggs dropped down. When more than one female was producing eggs simultaneously on a single root, there even arose doubt as to which certain of the fallen eggs should be credited. For the biological records the first season, 9 vines were used, averaging 3 separate roots each, but since 3 of these roots died, after they were planted, only 24 roots were actually used. Of these 3 were used for rearing gallicole progeny and 5 others were used for nymph production and fertilizer experiments on heavily infested vines, leaving 16 for individual records. In 1914 and 1915, only 4 vines were used each year to continue the individual series.

Many interesting habits were observed, but the behavior of the phylloxerae in the main did not differ from that observed under cellar conditions upon severed roots. Newly hatched larvæ mostly settled close to the eggshells they had vacated, but if there were any fresh lesions near by, the young larvæ often found their way to them and settled. Occasional movements of older individuals were observed, not only at the time of molting but at any time in the instars. These movements were generally in the direction of more succulent food. Occasionally egg-laying individuals shifted their positions without apparent injury, although this was sometimes followed by a temporary halt in the production of eggs. The production of nymphs occurred from June to October, as in the vineyard. The tendency of the nymphs to crawl up the root just before transforming was noticeable. Most of them could go no farther upward than the cylinder plugged with cotton, and so perforce had to transform into migrants at this point. A small percentage transformed at points farther down the root and did not appear to have made any upward migration. On the heavily infested roots, wanderers appeared from July to October. These roamed around the inside of the compartment, and succeeded in finding their way down through cracks in the soil of the lower pots, and infested the rootlets, especially those growing against the inside of the pots. After irrigation, cracks appeared in the soil around the inside of the pot, furnishing the wandering larvæ access to the rootlets. In no case was this infestation of any great extent, although large numbers of wandering larvæ were observed in several of the cages, and only a very small percentage, presumably, found their way to a new food supply. This fact has an important bearing upon the distribution of the insect as will be noted elsewhere. Although it appeared difficult for the insects to penetrate an inch of sand in the lower glass cylinder, the occurrence of large infestations immediately below the cylinder, coupled with evidences of only slight infestations on the

rootlets around the inside of the pots, showed that such a penetration had occurred. It was obvious in these instances, few though they were, that the heavy infestations could not have resulted from inoculations on rootlets from wanderers, because only a few nodosities occurred on the rootlets, showing a slight wanderer infestation, and not enough time had elapsed in the interim for the infestation present at the date of examination to be produced by so small a company of wandering larvæ. The phylloxeræ had no difficulty in finding their way through the upper cylinder to the root system of the upper pots through layers of cotton and sand each about half an inch thick. On the roots of the upper pot of cage V, Burger, there were, on November 26, 1913, upward of 1,600 hibernants disposed in large clusters on the main root. Since June of that year, the visible portions of four roots below had been well infested. Every one of those 1,600 hibernants was the progeny of phylloxeræ hatched on the visible part of the roots and which had penetrated the upper cylinders. It is obvious that a great many individuals penetrated the cylinders, as the scarcity of lesions showed that the greater part of the infestation was comparatively recent. Apparently a natural law against overcrowding comes into play, and migration was encouraged by the fact that the tuberosities on three of the four roots had become rotted and threatened to decay all the visible portions of those roots. As, on this vine, no infestation other than a few nodosities occurred below the cylinders in the lower pots, it would appear that the heavy migration had been entirely in an upward direction. As far as could be determined, there appeared no reason why the insects could not penetrate the lower cylinders just as easily as the upper ones, so the conclusion is that in most cases they did not make the attempt.

In the instances wherein phylloxeræ had undoubtedly penetrated the lower cylinders they were found to be close to the cylinder as if the packing of sand and cotton had been so loose that no effort was needed for the insect to force its way through. The sand in the upper cylinders, by reason of the weight of earth pressing upon it, always remained well packed and presented a barrier to the progress of the phylloxeræ. That they were able to surmount this barrier is shown by the large numbers present, and indicates that the upward migration was a well-defined movement. The possibility presented itself that infestations on the roots of the upper pots could have originated from wandering larvæ that had penetrated the soil of the upper pots in the same manner as they had obviously done in the lower pots of the cages. The absence of cracks except around the periphery of the soil in the pots and of nodositous infestations on the rootlets below taken in conjunction with the size of the infestations precludes this as the sole source of the inoculations of the upper pots.

Some of the lower pots of the cages were filled with quartz of mixed grades. This was done chiefly for the purpose of experimenting with liquid fertilizers as to the bearing of fertilizing substances upon the behavior of infested vines as an adjunct to similar vineyard experiments. Twelve out of 36 lower pots contained quartz. It was found that the wandering larvæ were able to descend to rootlets growing in the quartz as easily as to those growing in earth. On the other hand, the phylloxeræ were not able to exist on the larger roots in the quartz in appreciable numbers, as it appeared that they could not pass through the quartz when it was packed around the root. This is similar to the condition existing on very sandy soils, wherein the phylloxeræ are unable to travel when the sand becomes packed around the roots.

Table XIII indicates the incubation and development of the radicle on the roots of living vines.

TABLE XIII.—Incubation and development of radicle of the grape phylloxera on living vines, Walnut Creek, Calif., 1913–1915.

FIRST GENERATION, 1913.

Individual No.	Date egg deposited.	Date egg hatched.	Incubation period.	Date insect matured.	Growing period.	Total period of development.	Variety of vine and number of cage.	Average temperature.
			<i>Days.</i>		<i>Days.</i>	<i>Days.</i>		<i>° F.</i>
1	Apr. 29	May 14	15	June 8	25	40	Mission VII.....	60
2	May 28	June 6	9	June 25	19	28	do.....	67
3	do.....	do.....	9	do.....	19	28	do.....	67
4	do.....	do.....	9	June 26	20	29	do.....	67
5	do.....	do.....	9	June 28	22	31	do.....	67
6	do.....	do.....	9	June 29	23	32	do.....	67
7	do.....	do.....	9	June 30	24	33	do.....	67
8	do.....	do.....	9	do.....	24	33	do.....	67
9	do.....	do.....	9	do.....	24	33	do.....	67
10	June 14	June 22	8	July 5	13	21	Burger VI.....	69
11	do.....	do.....	8	July 8	16	24	do.....	69
12	do.....	June 23	9	July 7	14	23	do.....	69
13	do.....	June 22	8	July 9	17	25	do.....	69
14	do.....	June 24	10	July 14	20	30	do.....	69
15	June 15	do.....	9	do.....	20	29	do.....	69
16	do.....	do.....	9	July 15	21	30	do.....	69
17	do.....	June 26	11	July 18	22	33	do.....	69
18	June 16	do.....	10	July 21	25	35	do.....	69
19	June 8	June 17	9	July 9	22	31	Burger V.....	68
20	do.....	do.....	9	do.....	22	31	do.....	68
21	do.....	June 19	11	July 13	24	35	do.....	69
22	do.....	do.....	11	do.....	24	35	do.....	69
23	do.....	June 20	12	July 15	25	37	do.....	69
24	do.....	June 17	9	July 7	20	29	do.....	68
25	do.....	do.....	9	July 8	21	30	do.....	68
26	do.....	June 18	10	July 2	14	24	do.....	68
27	do.....	do.....	10	do.....	14	24	do.....	68
28	do.....	do.....	10	do.....	14	24	do.....	68
29	do.....	do.....	10	July 4	16	26	do.....	68
30	do.....	do.....	10	July 6	18	28	do.....	68
31	do.....	do.....	10	do.....	18	28	do.....	68
32	do.....	do.....	10	do.....	18	28	do.....	68
33	do.....	do.....	10	July 7	19	29	do.....	68
34	do.....	do.....	10	do.....	19	29	do.....	68
35	May 25	June 4	10	June 19	15	25	do.....	67
36	do.....	do.....	10	June 21	17	27	do.....	67
37	do.....	June 5	11	June 23	18	29	do.....	67
38	do.....	do.....	11	June 24	19	30	do.....	67
39	do.....	June 6	12	June 25	19	31	do.....	67
40	do.....	do.....	12	do.....	19	31	do.....	67
41	do.....	do.....	12	June 27	21	33	do.....	67
42	do.....	do.....	12	do.....	21	33	do.....	67
43	do.....	do.....	12	June 29	23	35	do.....	68
44	do.....	June 8	14	July 2	24	38	do.....	68
45	do.....	do.....	14	July 3	25	39	do.....	68

TABLE XIII.—Incubation and development of radicle of the grape phylloxera on living vines, Walnut Creek, Calif., 1913-1915—Continued.

SECOND GENERATION, 1913.

Individual No.	Date egg deposited.	Date egg hatched.	Incubation period.	Date insect matured.	Growing period.	Total period of development.	Variety of vine and number of cage.	Average temperature.
			Days.		Days.	Days.		° F.
1	June 10	June 20	10	July 8	18	28	Mission VII.....	68
2	June 11	June 19	8	do.	19	27	do.	68
3	June 12	do.	7	do.	19	26	do.	68
4	do.	June 20	8	July 11	21	29	do.	69
5	June 30	July 6	6	July 20	14	20	do.	70
6	do.	July 8	8	July 22	14	22	do.	70
7	do.	do.	8	July 23	15	23	do.	70
8	do.	do.	8	do.	15	23	do.	70
9	do.	do.	8	July 31	23	31	do.	71
10	do.	July 9	9	July 24	15	24	do.	70
11	do.	do.	9	July 25	16	25	do.	70
12	do.	do.	9	July 31	22	31	do.	71
13	July 1	do.	8	Aug. 4	26	34	do.	71
14	do.	do.	8	Aug. 7	29	37	do.	71
15	do.	do.	8	Aug. 11	33	41	do.	71
16	June 30	do.	9	Aug. 8	30	39	do.	71
17	June 26	July 3	7	July 21	18	25	Burger VI.....	70
18	do.	July 4	8	July 25	21	29	do.	70
19	do.	do.	8	July 26	22	30	do.	70
20	do.	do.	8	do.	22	29	do.	70
21	do.	do.	8	July 28	24	32	do.	70
22	do.	July 5	9	July 29	24	33	do.	70
23	do.	do.	9	July 31	26	35	do.	70
24	June 27	July 4	7	July 28	24	31	do.	70
25	do.	July 5	8	July 31	26	34	do.	70
26	June 30	do.	6	Aug. 8	23	29	Burger V.....	71
27	do.	July 6	6	Aug. 10	35	41	do.	71
28	do.	July 7	7	Aug. 12	36	43	do.	71
29	do.	do.	7	do.	36	43	do.	71
30	July 1	July 8	7	do.	35	42	do.	71
31	do.	do.	7	Aug. 13	36	43	do.	71
32	July 2	do.	6	Aug. 14	37	43	do.	71
33	do.	July 10	8	Aug. 18	39	47	do.	71

THIRD GENERATION, 1913.

1	July 23	July 31	8	Aug. 25	25	33	Thompson's Seedless I..	71
2	July 28	Aug. 5	8	Aug. 28	23	31	Muscat IV.....	71
3	July 29	Aug. 7	9	Aug. 30	23	32	do.	71
4	do.	do.	9	Sept. 1	25	34	do.	71
5	do.	Aug. 8	10	Sept. 3	26	36	do.	71

FOURTH GENERATION, 1913-14.

1	Aug. 26	Sept. 3	8	(²)	-----	-----	Thompson's Seedless I..	³ 71
2	Sept. 1	Sept. 8	7	Sept. 18	10	17	Champini IX.....	70
3	do.	Sept. 9	8	Sept. 22	13	21	do.	69
4	do.	Sept. 10	9	Sept. 30	20	29	do.	69
5	do.	Sept. 23	-----	Apr. 6	195	-----	Muscat IV.....	-----
6	do.	do.	-----	Apr. 9	198	-----	do.	-----
7	do.	Sept. 24	-----	Oct. 24	30	-----	do.	66
8	do.	do.	-----	Apr. 6	194	-----	do.	-----
9	do.	do.	-----	Apr. 7	195	-----	do.	-----
10	do.	do.	-----	May 20	238	-----	do.	-----
11	do.	do.	-----	Apr. 15	203	-----	do.	-----
12	do.	Sept. 25	-----	Apr. 24	211	-----	do.	-----
13	do.	do.	-----	Apr. 28	215	-----	do.	-----

FIFTH GENERATION, 1914.

1	Apr. 25	May 9	14	May 28	19	33	Muscat IV.....	62
2	Apr. 26	do.	13	do.	19	32	do.	62
3	do.	do.	13	June 2	24	37	do.	63
4	Apr. 27	do.	12	June 1	23	35	do.	63
5	do.	do.	12	June 2	24	36	do.	63
6	Apr. 28	do.	11	do.	24	35	do.	63
7	do.	do.	11	June 3	25	36	do.	63

¹ Indicates winged migrants. ² Hibernant. ³ Indicates average temperature of incubation period alone.

TABLE XIII.—*Incubation and development of radicle of the grape phylloxera on living vines, Walnut Creek, Calif., 1913-1915—Continued.*

SIXTH GENERATION, 1914.

Individual No.	Date egg deposited.	Date egg hatched.	Incubation period.	Date insect matured.	Growing period.	Total period of development.	Variety of vine and number of cage.	Average temperature.
			<i>Days.</i>		<i>Days.</i>	<i>Days.</i>		<i>° F.</i>
1	May 29	June 7	9	June 24	17	26	Muscat IXA.....	67
2	June 2	June 8	6	July 1	23	29	Grenache IIA.....	68
3	June 9	June 19	10	July 10	21	31	Muscat IXA.....	69
4	..do....	June 20	11	July 26	36	47	..do.....	69

SEVENTH GENERATION, 1914.

1	June 24	July 3	9	July 23	20	29	Muscat IXA.....	70
2	..do....	July 4	10	July 29	25	35	..do.....	71
3	June 25	July 3	8	July 23	20	28	..do.....	70
4	..do....	July 4	9	July 30	26	35	..do.....	71
5	June 26	..do....	8	July 28	24	32	..do.....	71
6	..do....	..do....	8	July 30	26	34	..do.....	71
7	July 1	July 9	8	July 29	20	28	Grenache IIA.....	72
8	July 2	July 11	9	..do....	18	27	..do.....	72
9	..do....	..do....	9	Aug. 1	21	30	..do.....	72
10	July 3	..do....	8	Aug. 3	23	31	..do.....	72
11	..do....	..do....	8	..do....	23	31	..do.....	72

EIGHTH GENERATION, 1914-15.

1	Aug. 17	Aug. 24	7	Sept. 16	23	30	Muscat XXX.....	70
2	..do....	..do....	7	..do....	23	30	..do.....	70
3	..do....	Aug. 25	8	Sept. 26	32	40	..do.....	69
4	..do....	..do....	8	Mar. 26	213	221	..do.....	3 72
5	..do....	..do....	8	Mar. 30	217	225	..do.....	3 72
6	..do....	..do....	8	Apr. 3	221	229	..do.....	3 72
7	..do....	..do....	8	Apr. 4	222	230	..do.....	3 72
8	..do....	..do....	8	(¹)	.....	.....	..do.....	3 72
9	..do....	Aug. 26	9	(¹)	.....	.....	..do.....	3 72

NINTH GENERATION, 1914-15.

1	Sept. 16	Sept. 27	11	(¹)	.....	.....	Muscat XIX.....	3 72
2	..do....	..do....	11	Apr. 11	196	207	..do.....	3 72

NINTH GENERATION, 1915.

1	Mar. 31	Apr. 19	19	May 22	33	52	Carignan XXIX.....	57
2	..do....	..do....	19	May 23	34	53	..do.....	57
3	..do....	..do....	19	May 24	35	54	..do.....	57
4	..do....	..do....	19	May 25	36	55	..do.....	57

TENTH GENERATION, 1915.

1	May 23	June 3	11	June 24	21	32	Carignan XXIX.....	66
2	May 27	June 6	10	July 1	25	35	Zinfandel XXIIIA.....	67

ELEVENTH GENERATION, 1915.

1	July 9	July 15	6	Aug. 10	26	32	Zinfandel XXIIIA.....	73
2	.....	.....	.....	July 29	.....	.....	Carignan XXIX.....	.....
3	.....	.....	.....	..do....	.....	.....	..do.....	.....

TWELFTH GENERATION, 1915.

1	Aug. 2	Aug. 9	7	Sept. 8	30	37	Zinfandel XXXVI.....	72
2	..do....	Aug. 10	8	Sept. 9	30	38	..do.....	72
3	..do....	Aug. 9	7	Sept. 10	32	39	..do.....	72
4	Aug. 4	Aug. 11	7	..do....	30	37	..do.....	72
5	Aug. 16	Aug. 24	8	.....	.....	.....	Zinfandel XXIIIA.....	.....
6	..do....	Aug. 25	9	.....	.....	.....	..do.....	.....
7	Aug. 17	..do....	8	.....	.....	.....	..do.....	.....
8	Aug. 18	Aug. 27	9	.....	.....	.....	..do.....	.....
9	Aug. 19	..do....	8	.....	.....	.....	..do.....	.....

¹ Indicates average temperature of incubation period alone.⁴ Died, 1915.

For the first generation, eggs deposited by adult hibernants were secured from a Zinfandel vineyard, and thereafter only eggs deposited in the cages and of known generations were used in the inoculations.

The average growing periods of the summer generations of wingless aphids varied from 34.5 to 18.25 days, but in all except two generations this period ranged between 18.25 and 24.20 days. Individuals varied between 36 and 10 days. The winged forms developed more slowly than the wingless, nine individuals averaging $34\frac{1}{2}$ days. The hibernants developed in an average of $6\frac{3}{4}$ months.

Eggs were placed for the most part on roots never before infested, and tuberosities usually followed rapidly after the hatching of the larvæ. Nodosities were formed upon side rootlets. The main roots were all between one-sixth and one-third of an inch in diameter.

It was found that about 40 per cent of the larvæ remained on the exposed portions of the roots, the rest finding their way to the other portions. In spring a large percentage and in summer and autumn a smaller percentage of larvæ settled close beside the eggshells from which they had issued. In spring the larvæ did not display a tendency to roam, but in summer and autumn they wandered considerably, especially if the root had begun to decay or was drying too rapidly. Similar conditions occur in vineyards, and it is in summer and autumn that the typical wandering larvæ are found.

Excluding the winged migrants and the hibernated individuals, the summary of the growing period of all the phylloxeræ developing on living roots during the years 1913, 1914, and 1915 is recorded in Table XIV.

TABLE XIV.—*Summary of Table XIII.*

Number of individuals	-----	114
Average period of growth	-----days--	22. 15
Maximum period of growth	-----do---	36
Minimum period of growth	-----do---	10

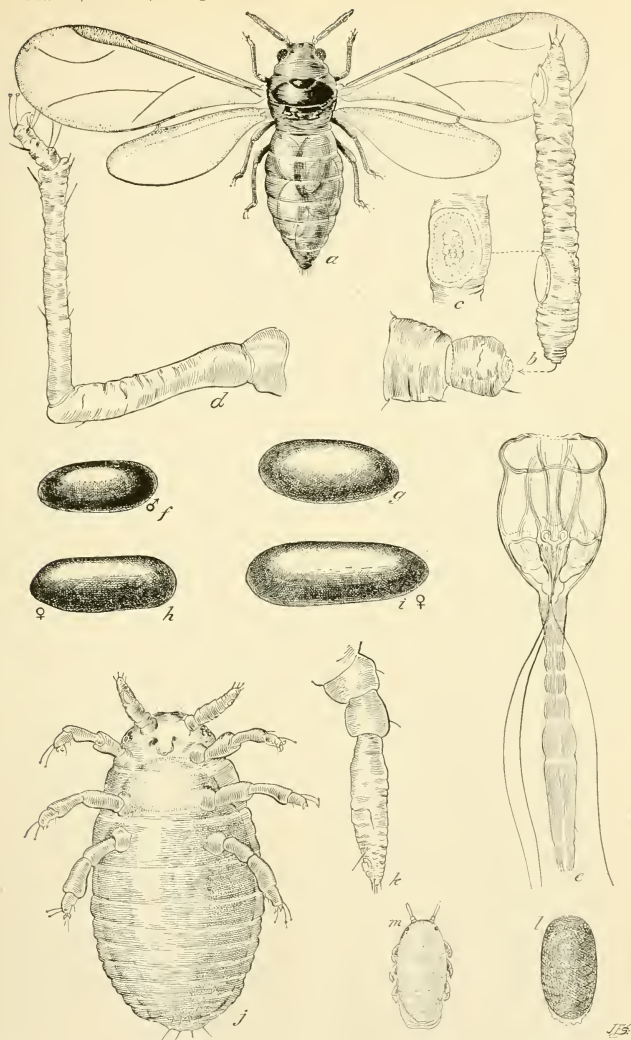
Taking into consideration the individuals removed before they attained their full development, the average growing period is to be estimated at about 25 days. The cellar experiments with severed pieces of roots in 1911 and 1912 combined yielded an average of 30.57 days, and the experiments in the cellar and incubator combined in 1913 averaged 34.16 days. The cellar temperatures of 1911 and 1912 averaged about $11\frac{1}{2}^{\circ}$ F. lower than the combined cage temperatures for the period 1913–1915 for the months from May to October, inclusive. The cellar temperatures for 1913 averaged about $11\frac{1}{2}^{\circ}$ lower than the incubator temperatures for 1913 and about $\frac{1}{2}^{\circ}$ higher than the cage temperatures for that year.

In the cellar and incubator during 1913 the phylloxerae developed, on the average, more slowly than in the cellar during 1911 and 1912, notwithstanding higher temperatures in 1913. This resulted from the fact that the food supply was much more succulent in 1911 and 1912. Likewise the phylloxerae developed much more rapidly in the cages in 1913-1915 than in the cellar and incubator combined in 1913, when the temperatures differed slightly (the difference in favor of the cages being about 1° daily). This also was due to the superior food of the living vines. In comparing the phylloxera development in the cellar in 1911-12 with that in the cages in 1913-1915, it would appear that both temperature and food influenced the more rapid development observed in the cages. For 1911 alone the average growing period was 29.37 days. This growth took place on succulent roots, to all appearances as succulent as the living roots upon which were reared the 1913-1915 phylloxerae, which averaged about a 25-day period, under a temperature averaging $4\frac{1}{2}^{\circ}$ in excess of that obtaining in the cellar in 1911. It would be natural to ascribe the faster growth in the cages to the higher temperatures, but in view of the discrepancies noted above in connection with the 1913 cellar and incubator observations, the writers are inclined to believe that the living roots afforded better nourishment to the phylloxerae than did the severed roots of 1911 and that the higher temperatures of 1913 had less influence than might appear in bringing about such a difference in the growing periods.

Excepting for a few isolated instances, the phylloxerae on living roots developed more rapidly on nodosities and tuberosities than on the normal surface of the root. On nodosities development was the most rapid, noticeably more rapid than on tuberosities, and the more fleshy the swelling the more rapid was the aphid's growth.

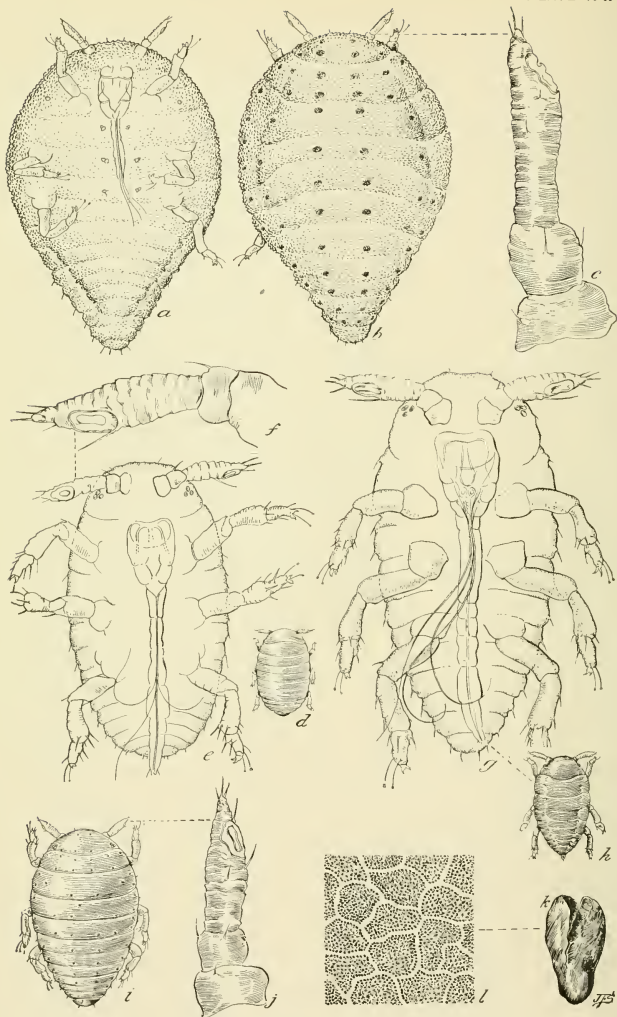
DESCRIPTION OF STAGES.

The egg.—When first laid, the radicle egg (Pls. VIII, *g*; IX, *k*, *l*) is lemon yellow, about twice as long as wide, oval, both ends rather bluntly rounded, the micropylar end a little more abruptly so. Thirty-six eggs laid by newly matured adults August 30 and September 6, 1911, averaged 0.348 mm. in length and 0.173 mm. in width, with maxima, respectively, of 0.36 and 0.18 mm., and minima, respectively, of 0.34 and 0.17 mm. Of 25 eggs laid by overwintered radicles near the end of their laying period, the maximum length was 0.32 mm., the maximum width 0.18 mm., the minimum length 0.20 mm., and the minimum width 0.12 mm., the average length 0.26 mm., and the average width 0.14 mm. Thus it appears that the size of the eggs laid by individuals decreases toward the end of their egg-laying



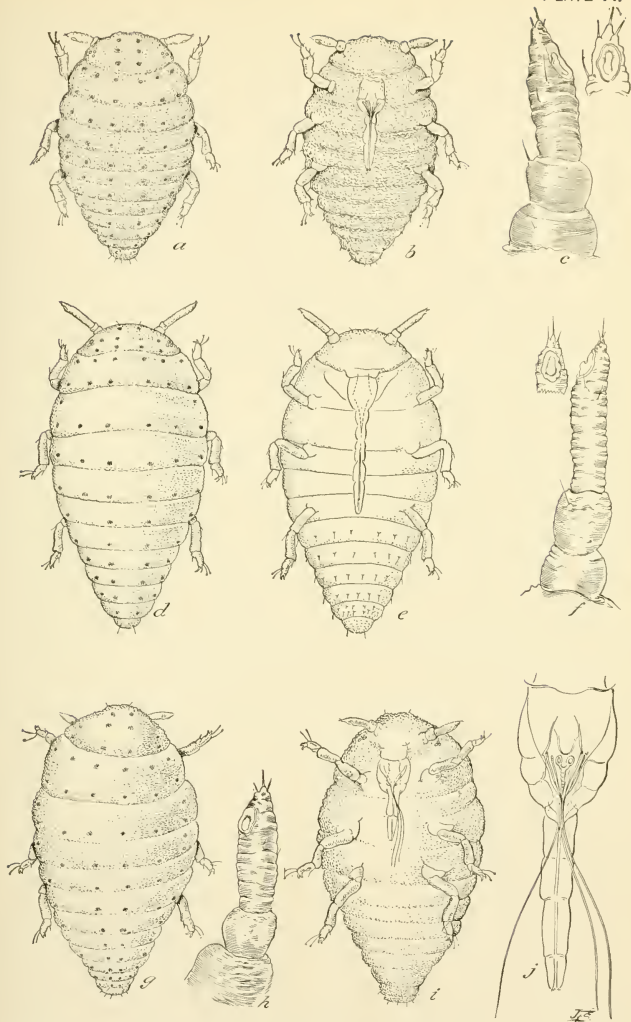
THE GRAPE PHYLLOXERA IN CALIFORNIA.

Phylloxera vitifoliae: a-e, Winged migrant; a, dorsal view; b, antenna; c, basal sensorium of antennal segment III; d, hind leg; e, beak; f, male egg; g, radicle egg; h, i, female eggs; j, k, l, sexed female; j, enlarged ventral view showing contained winter egg; k, antenna; l, newly hatched female; m, mature male just after ecdysis.



THE GRAPE PHYLLOXERA IN CALIFORNIA.

Phylloxera vitifoliae: a, b, c, Adult radicle; a, ventral view (beak shown telescoped); b, dorsal view; c, antenna; d, e, f, hibernant larva; d, dorsal view; e, ventral view; f, antenna; g, h, newly hatched (first-instar) radicle; g, ventral view; h, dorsal view; i, j, second-instar radicle; i, dorsal view; j, antenna; k, l, radicle egg corium; k, whole shell; l, section to show structure.



THE GRAPE PHYLLOXERA IN CALIFORNIA.

Phylloxera vitifoliae: a, b, c, Third-instar radicle; a, dorsal view; b, ventral view; c, left antenna; d, e, f, pre nymph (third instar of winged form); d, dorsal view; e, ventral view; f, left antenna; g-j, fourth-instar radicle; g, dorsal view; h, left antenna; i, ventral view (beak shown telescoped); j, beak.

period. Toward the period of hatching the egg becomes darker and the eyespots of the embryo become visible.

The larva.—In hatching, the young larva (Pl. IX, *g, h*) splits the eggshell from the micropyle lengthwise to about three-fourths of its length. This splitting is more or less gradual and is caused by the thorax and head of the young phylloxera bursting the shell and then gradually enlarging the crack. The larva poises itself at an angle of 45° , with legs and antennæ appressed to the body, and slowly eases its way out. It seems to rely simply on a slow side-wise body movement to free itself of the shell. When freed, it spreads the appendages and is then able to walk off. The newly hatched larva is of a pale lemon yellow, with dark claret-colored eyes, composed each of three circular facets and placed in the form of the angles of an equilateral triangle. The body segmentation is quite distinct, more so than in later instars. The shape is oval and very flat. The antennæ, as in all forms of the grape phylloxera, are three-jointed. The terminal joint is twice as long as the two basal combined. Near the apex of the third joint occurs a circular sensorium. The beak in early generations reaches to the penultimate or antipenultimate body segment, and in later generations protrudes beyond the caudal segment of the abdomen. The legs and antennæ bear hairs. Table XV gives measurements for five newly hatched individuals.

TABLE XV.—*Measurements of newly hatched radicles of the grape phylloxera, Walnut Creek, Calif., Oct. 23, 1914.*

Individual No.	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>
1.....	0.359	0.176	0.1964	0.0679	0.0571	.....	0.0161	0.0705	.....
2.....	.327	.179	.2036	.....	.....	0.0169	.0143	.0625	.....
3.....	.....	.....	.....	.0562	.0429	.0214	.0196	.0680	.....
4.....	.359	.189	.2152	.0580	.0491	.0232	.0180	.0705	.....
5.....	.341	.190	.2107	.0566	.0455	.0188	.0188	.0634	0.0231
6.....	.....	.....	.....	.0554	.0491	.0179	.0152	.0670	.0238

The young phylloxerae hatching in spring have shorter beaks than those which hatch in the fall, the beaks in spring averaging in length about 0.155 mm.

The first molt does not take place until more than half of the growing period is passed. The molting of the radicles is a procedure quite similar in detail to the hatching from the egg. After each molt the individual for about 24 hours is brighter in color than at any other time during the instar. After the first molt the phylloxera changes from oval or suboval to pyriform in shape (Pl. IX, *i, j*).

Table XVI gives measurements for four individuals of the second-instar radicleole.

TABLE XVI.—Measurements of second-instar radicleoles of the grape phylloxera, Walnut Creek, Calif.

Individual No.	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
1.....	Mm. 0.419	Mm. 0.234	Mm. 0.154	Mm. 0.0625	Mm. 0.0526	Mm. 0.0190	Mm. 0.0204	Mm. 0.0586	Mm.
2.....	.448	.....	.....	.0624	.0518	.0205	.0205	.0589	.....
3.....	.439	.257	.113	.....	.....	.....	.....	.....	.....
4.....	.499	.270	.168	.....	.....	.....	.....	.....	0.0171

¹ Teleseoped.

The roughened tubercular areas on the dorsal surface are more conspicuous after the first molt, and a rapid increase in bulk is apparent during the second instar.

The second, third, and fourth molts occur at practically equidistant periods. Under highest temperatures and optimum food conditions, these instars are passed in about two days apiece. Under a temperature of 58° F. from three to eight days elapse between molts, the average being about five and one-half days.

Table XVII gives the measurements of five individuals of the third instar.

TABLE XVII.—Measurements of third-instar radicleoles of the grape phylloxera, Walnut Creek, Calif.

Individual No. ¹	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
1.....	Mm. 0.592	Mm. 0.303	Mm. 0.178	Mm. 0.0699	Mm. 0.0607	Mm. 0.0202	Mm. 0.0321	Mm. 0.0616	Mm. 0.0
2.....	.524	.312	.164	.....	.....	.0252	.0207	.0568	.0144
3.....	.522	.332	.179	.0739	.0622	.....	.....	.....	.....
4.....	.649	.355	.155	.0732	.0687	.0241	.0205	.0634	.....
5.....	.....	.....	.....	.0758	.0660	.0197	.0187	.0589	.0177
6.....	.648	.371	.145	.0741	.0692	.0206	.0194	.0598	.0186
.....	.....	.....	.....	.....	.....	.....	.....	.....	.0190

¹ Individuals 1-3, newly molted; 4, two days after molt; 5, three days after molt.

During the third instar (Pl. X, *a*, *b*, *c*) the increase in bulk continues rapidly. The dorsal tubercular areas are larger than in the previous instar, but in color and shape no differences appear.

Table XVIII indicates the measurements of seven individuals of the fourth (penultimate) instar.

TABLE XVIII.—Measurements of fourth-instar radiclecoles of the grape phylloxera, Walnut Creek, Calif.

Individual No. ¹	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>
1.....	0.919	0.517	.....	0.0848	0.0687	0.0321	0.0259	0.0669	.....
2.....	.851	.528	.....	.....	.....	.0321	.0277	.0571	.....
3.....	.824	.579	.....	.0830	.0749	.0276	.0241	.0768	0.0212
4.....	.615	.500	0.172	.....	.....	.0306	.0261	.0748	.0167
5.....	.....	.162	.....	.....	.....	.0297	.0248	.0721	.0162
6.....	.753	.426	.160	.0802	.0671	.....	.....	.....	.....
7 ²	.700	.....	.....	.....	.....	.....	.....	.....	.....

¹ Individuals 1-3 were measured toward the end of the instar, and individuals 4-7 very shortly after molting.

² Maximum height, 0.3 mm.

A very obvious growth takes place during the fourth instar (Pl. X, *g-j*). At the end of this instar the phylloxera casts its last skin and issues therefrom as an adult. The adults, except immediately following the molt, are never as pale as the immature forms. They may be distinguished from fourth-instar individuals by two longitudinal furrows on the thorax and by the relatively larger dorsal tubercular areas. The color varies from a light green to a dark purplish brown in living specimens. This variation is to a great degree dependent on the food supply. On fresh, fleshy nodosities the insects mostly are pale green with the tubercular areas very noticeable. On tuberosities, or on the normal surface of a vigorous root, the color is yellowish green, olive green, or light brown, with the tubercular areas often less evident.

On roots of poor quality the adults are brown or orange and the tubercular areas hardly perceptible to the naked eye. After weeks of egg production old adults become brown or purplish brown. In shape the adults while not engaged in egg laying are hemispherical or short oval, about equally rounded at either extremity, but while an egg is being passed the insect assumes a pyriform shape and the caudal end is much tapered and extended.

Mature radiclecole.

Pl. IX, *a, b, c.*

Color varying from pale green and pale yellow to deep purplish brown, dependent on character of food and age of individual; shape hemispherical, short oval, pyriform while passing the ova; body obscurely glabrous, often appearing to be coated on the dorsum with a very fine whitish powder; under side of abdomen paler than upper. Body about twice as long as wide, widest at middle of mesothorax; highest at about cephalic third; body flattening both cephalad and caudad from this point. Head with dusky central area; eyes dark red, each composed of three circular facets, arranged in form of an equilateral triangle; antennae pale, not quite reaching posterior margin of head, composed of three joints, of which the two basal are subequal in length but

joint 1 wider than joint 2; third joint about twice as long as the two basal combined and bearing a single oval sensorium near apex; all three joints bearing hairs. Beak pale, base and tip shining and dusky, reaching to second or third abdominal tergite; in specimens examined after they had transfixed the beak into the roots, this organ appears to be shorter, due to the telescoping of the sheath from the action of transfixing.

Mesothorax largest segment of body, twice as long as prothorax, which is next largest; mesothorax divided into two sections by transverse fold. Thoracic segments having median portions raised above lateral portions by means of two longitudinal curved folds. Metathorax very similar above to any of first five abdominal segments. Legs in pale specimens slightly darker than abdomen, coxæ dusky.

Sixth abdominal segment produced conically at each of its posterior angles and narrowed basally; caudal segment twice as long as broad, bluntly rounded, with a small central emargination and fringed with a marginal row of pale weak hairs.

The dorsum of the body bears six longitudinal rows of dusky circular tubercular areas, which under magnification appear as thickenings and roughenings of the epidermis, and each of these is surmounted by a single spine.

Table XIX gives measurements of the adult radicle.

TABLE XIX.—*Measurements of mature radicle of the grape phylloxera, Walnut Creek, Calif.*

Individual No.	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>
1.....	0.854	0.502		0.0795	0.0786	0.0223	0.0251	0.0661	0.0224
2.....	.878	.549	0.281	.0804	.0759	.0252	.0243	.0660	.0195
3.....	1.011	.584		.0839	.0718	.0260	.0230	.0673	.0196
4.....	.997	.558		.0875	.0768	.0197	.0230	.0705	.0205
5.....	.942	.593							
6.....	.783	.507							
7.....	.778	.503							
8.....	.763	.455							
9.....	.734	.433							
10.....	.714	.448							
11.....	.712	.392							
12.....	.686	.408							
13.....	.631	.416							
14.....	.582	.352							

Measurements of beaks from nine adult hibernants were made March 18, 1915. Of these six, fixed in the root tissue, measured 0.276, 0.243, 0.260, 0.252, 0.198, and 0.179 mm., respectively. The other three, not fixed since casting their last skin, measured 0.329, 0.317, and 0.299 mm., respectively. The basal joints of the rostrum are telescoped when the beak is thrust into the root.

It is obvious from an inspection of Table XIX that the adult radicles vary greatly in size. This variation occurs whatever kind of food supply the phylloxerae are getting, although the average size is larger on good succulent food than on that of poorer quality. Individuals 5 to 14 in Table XIX were all taken the same day (Mar. 18)

from equally succulent pieces of severed roots. They show a considerable variation in dimensions, but, being hibernants, their average dimensions are less than those of the summer generations under equally favorable food-supply conditions; for among the hibernant adults there always may be found a considerable number of small-sized individuals which evidently owe their physical inferiority to the vicissitudes of the long hibernation period. Radicicoles raised on fleshy and succulent nodosities attain an average size of about 1 by 0.55 mm., those raised during the summer on other parts of the root system average slightly less, and the hibernant individuals average 0.75 by 0.50 mm.

Radicicole molts.—The radicle, in common with other forms of the phylloxera, invariably molts four times.

In 1914 and 1915 records of molts were taken, and Tables XX and XXI indicate molting records of 20 individuals reared on severed roots in the laboratory cellar during the summer of 1914.

TABLE XX.—*Molting records of 20 radicoles of the grape phylloxera, summer of 1914, Walnut Creek, Calif.*

Individual No.	Date egg hatched.	Date of first molt.	First instar.	Date of second molt.	Second instar.	Date of third molt.	Third instar.	Date of fourth molt.	Fourth instar.	Total growing period.	Average temperature.
			<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	<i>Days.</i>	<i>° F.</i>
1	July 22	Aug. 6	15	Aug. 9	3	Aug. 11	2	Aug. 14	3	23	68
2	do.	Aug. 7	16	do.	2	do.	2	do.	3	23	68
3	July 23	Aug. 6	14	do.	3	Aug. 13	4	Aug. 16	3	24	68
4	do.	do.	14	do.							
5	July 24	Aug. 7	14	Aug. 9	2	Aug. 11	2	Aug. 14	3	21	68
6	July 25	Aug. 4	10	Aug. 6	2	Aug. 8	2	Aug. 9	1	15	68
7	do.	do.	10	do.	2	do.	2	Aug. 11	3	17	68
8	do.	Aug. 5	11	Aug. 8	3	Aug. 9	1	do.	2	17	68
9	do.	do.	11	do.	3	Aug. 11	3	Aug. 13	2	19	68
10	do.	do.	11	Aug. 9	4	Aug. 12	3	Aug. 14	2	20	68
11	do.	Aug. 6	12	Aug. 8	2	Aug. 11	3	Aug. 13	2	19	68
12	do.	do.	12	do.	2	do.	3	Aug. 14	3	20	68
13	do.	Aug. 5	11	do.	3	Aug. 9	1	Aug. 11	2	17	68
14	do.	Aug. 7	13	Aug. 10	3						
15	do.	Aug. 8	14	do.	2	Aug. 13	3	Aug. 15	2	21	68
16	do.	do.	14	do.	2	Aug. 12	2	do.	3	21	68
17	do.	Aug. 9	15	Aug. 13	4	Aug. 15	2	Aug. 18	3	24	68
18	do.	Aug. 11	17	Aug. 14	3	Aug. 17	3	do.	1	24	68
19	do.	Aug. 13	19	Aug. 20	7	Aug. 24	4	Aug. 28	4	34	68
20	do.										

¹ Hibernant died unmolted Oct. 11.

TABLE XXI.—*Summary of Table XX.*

	Average period.	Maximum period.	Minimum period.
	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
First instar, 19 individuals	13.3	19	10
Second instar, 18 individuals	2.9	7	2
Third instar, 17 individuals	2.5	4	1
Fourth instar, 17 individuals	2.5	4	1
Developmental period, 17 individuals	21.2	34	15

All the individuals utilized in this experiment were reared on severed pieces of roots in a petri dish under cellar conditions. Individuals 19 and 20 lived on a much poorer root than the others, and thus is explained the relatively slow growth (34 days) of the one and the early hibernation of the other. Individuals 4 and 14 moved away after their first and second molts, respectively. It will be observed from the summary that the average period of the first instar (13.3 days) is considerably longer than is that of the three succeeding instars combined (7.9 days). The comparative periods of the instars are about constant; that is, an individual with a short first instar will have short succeeding instars and one with a long first instar will have long succeeding instars.

The records of Table XX were made in midsummer at a temperature of 68° F. In the soil at such a time of the year the temperature is higher and the development of the phylloxera more rapid, while in spring and late fall the development is correspondingly slower. The developmental period of the hibernated larvæ varies greatly, not so much from temperature as from other causes. There is an average period of two and one-half weeks from the commencement of feeding to the shedding of the first skin, and after that an average period of three weeks between the casting of the first skin and the shedding of the fourth, the second, third, and fourth instars occupying an average space of a week each. As summer progresses the development of the radicles becomes accelerated, as may be observed from Table XXII.

TABLE XXII.—*Molting records of radicles of the grape phylloxera, March to July, 1915, Walnut Creek, Calif.*

Individual No.	Date egg hatched.	Date of first molt.	First instar.	Date of second molt.	Second instar.	Date of third molt.	Third instar.	Date of fourth molt.	Fourth instar.	Total growing period.	Average temperature.	Generation.
			<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	<i>Days.</i>	<i>° F.</i>	
1.....	Mar. 19	Apr. 3	15	Apr. 10	7	Apr. 16	6	Apr. 22	6	34	58.25	A.
2.....	...do....	Apr. 7	19	...do....	3	...do....	6	...do....	6	34	58.25	A.
3.....	...do....	Apr. 8	20	Apr. 13	5	Apr. 18	5	Apr. 23	5	35	58.25	A.
4.....	...do....	Apr. 10	22	Apr. 17	7	Apr. 21	4	Apr. 25	4	37	58.25	A.
5.....	May 11	May 27	16	May 30	3	June 1	2	June 5	4	25	61	B.
6.....	...do....	...do....	16	...do....	3	...do....	2	...do....	4	25	61	B.
7.....	May 23	June 7	15	June 10	3	June 13	3	June 16	3	24	63	B.
8.....	June 16	June 27	11	June 30	3	July 1	1	July 4	3	18	65	C.
9.....	...do....	June 30	14	July 2	2	July 4	2	July 9	5	23	65	C.
10.....	...do....	July 3	17	July 6	3	July 9	3	July 10	1	24	65	C.

The individuals enumerated in Table XXII were reared under cellar conditions on equally succulent pieces of severed roots. Table XXII, both by itself and taken in conjunction with Tables XX and XXI, indicates the influence of temperature upon the development of the radicle under equal food conditions. Under a temperature of 58.25° F. the period of growth averaged 35 days, under an aver-

age of 61.75° F. this period was 24.75 days, under 65° F. it was almost 22 days, and under 68° F. it was lowered to 20.3 days (individual on unthrifty root disregarded). Under the lower temperatures all the instars are correspondingly longer than under the highest midsummer temperature, but the first instar is proportionately less lengthened than are those following it, a phenomenon that becomes quite apparent in the case of the hibernants, provided their first instar be considered in a restricted sense to cover only that period between the time when they commence feeding in spring and the date of the first molt. The hibernant feeds for two and one-half weeks before and for three weeks after its first molt, while in midsummer the larva feeds for 13 days before and for 8 days after its first molt before it matures.

MAXIMUM AND MINIMUM GENERATIONS YEARLY.

In 1911 overwintered adult radicles matured at the end of April, throughout May and June, and as late as July 7. Eggs of the first generation were deposited from the end of April until October 1. From the earliest eggs there followed seven complete generations from hibernant to hibernant inside of the one year. No observations were taken of the hatching of the late eggs deposited by late first-generation phylloxerae in September, but in the light of contemporary observations on individuals of later generations there is no doubt that a certain percentage of these late eggs would have hatched into hibernants, thus giving a minimum of one generation per annum. In 1915, taking advantage of a hibernant which matured exceptionally early in the spring, it was possible to secure eight complete generations within the year. Table XXIII records the development of these generations.

TABLE XXIII.—*Maximum series of generations of radicles of the grape phylloxera, reared under cellar conditions, Walnut Creek, Calif., 1915.*

Generation No.	Date of egg deposition.	Date of egg hatching.	Date insect matured.	Generation cycle.	Temperature (average).
				Days.	° F.
1 ¹	— —, 1914	— —, 1914	Feb. 26, 1915	.....	.....
2.....	Feb. 26, 1915	Mar. 19, 1915	Apr. 22, 1915	55	58.25
3.....	Apr. 27, 1915	May 11, 1915	June 5, 1915	39	61.20
4.....	June 7, 1915	June 16, 1915	July 4, 1915	27	64.50
5.....	July 5, 1915	July 14, 1915	July 28, 1915	23	69.50
6.....	July 28, 1915	Aug. 4, 1915	Aug. 23, 1915	26	68.50
7.....	Aug. 23, 1915	Aug. 31, 1915	Sept. 23, 1915	31	67.00
8.....	Sept. 25, 1915	Oct. 7, 1915	Oct. 27, 1915	32	62.50
9 ¹	Oct. 27, 1915	Nov. 10, 1915	— —, 1916	.....	.....

¹ Hibernant.

In this experiment the food supplied to the phylloxera was, as far as one could judge, of equal quality and very nourishing. The influence of temperature is noticeable.

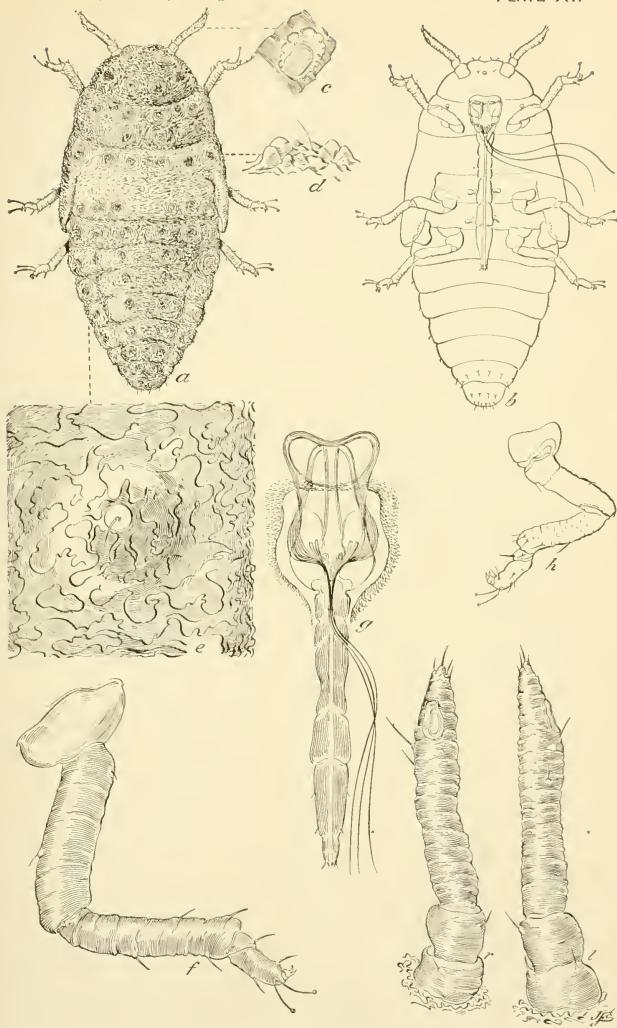
In observations with phylloxeræ developing on living vines there were secured in a period of three years 13 generations, an average of a little over four generations a year, but had the earliest eggs of each generation been successfully utilized, and had it been possible to start the first of the three seasons with the earliest eggs procurable in the vineyards, there is no doubt that six, and possibly seven, generations could have been developed each year.

Considering that the hibernant generation occupies a period of half a year, it is apparent that if seven generations are to be produced in a year, the other six must be passed in an average maximum of one month apiece. In summer phylloxeræ have been reared from egg deposition to maturity in 21 days, but in April, May, and October the cycle rarely falls below 35 days, so that in the six-month period, April 15 to October 15, the average maximum cycle is roughly 30 days. Thus, in the vineyard, even on vines that move early in spring, it is probable that more than seven generations rarely take place in 12 months. The period, October 15 to April 15, best represents the cycle of the wintering generation, although these dates are somewhat arbitrary.

Under vineyard conditions it is always possible to find hibernant phylloxeræ as late as the beginning of June. It is also possible to find insects going into hibernation as early as September 20. Since the mature radicles deposit eggs for periods exceeding three months, it can be seen readily that the latest eggs of a radicle hibernant maturing in June may develop larvæ which proceed to hibernate. A minimum of one generation a year thus may occur. Observations indicate that this minimum of one generation is not common, even on moribund vines with innutritious roots.

WANDERING RADICOLE LARVÆ OR "WANDERERS."

By the term "wanderers" are designated those forms (almost all newly hatched larvæ) which forsake the root on which they issued from the egg and seek to reach the surface of the soil or to pass through the soil itself, with the object of finding new food. Those that strive to reach the surface exhibit in their efforts a very marked positive phototropism. It would appear that their first movement is simply one of ascending the root and that as soon as they are brought into the focus of a ray of light they immediately make it their goal, and thus finally ascend to the surface. The initial wandering movement comes irrespective of light rays, but as soon as these rays are brought to bear the activity is very pronounced. The conclusion is that the production of individuals destined to wander is due to a combination of influences more than to any single influence—the crowded condition of the phylloxeræ in summer, the decaying of the roots, especially the fleshy surface rootlets, found on



THE GRAPE PHYLLOXERA IN CALIFORNIA.

Phylloxera vitifolae: *a*, Nymph, dorsal view; *b*, outline ventral view of same; *c*, enlarged sensorium on antennae; *d*, enlarged tubercle with spine; *e*, microscopic structural view of tubercle; *f*, hind leg; *g*, beak showing structure; *h*, middle leg; *i*, right antenna; *l*, left antenna.

phylloxerated vines, the rising temperature, and the intrinsic vigor of the vine encouraging emigration.

Apparently the young produced from the eggs deposited by overwintered females do not become wanderers, but those of later generations may, and many wandering larvæ produced late in the autumn settle on roots and hibernate.

Wandering larvæ play an important part in the diffusion of phylloxera.

THE NYMPH AND WINGED FORM.

DEVELOPMENT.

The individuals which are destined to become winged are termed in their third instar "prenymphs" and in their fourth instar "nymphs." They are produced from eggs deposited by adult radicles, and until after their second molt differ in nowise from the individuals destined to remain wingless; neither is there any difference in the eggs from which the two types hatch. In their third instar the prenympths (Pl. X, *d*, *e*, *f*) differ from the radicles of that instar in that the former have more elongate and narrower bodies and longer antennæ and legs. The prenympths are generally pale greenish yellow, and their appendages appear quite dusky in comparison. Table XXIV gives measurements of four prenympths.

TABLE XXIV.—*Measurements of prenympths of the grape phylloxera, Walnut Creek, Calif.*

Individual No. ¹	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
1.....	<i>Mm.</i> 0.805	<i>Mm.</i> 0.405	<i>Mm.</i> 0.357	<i>Mm.</i> 0.0948	<i>Mm.</i> 0.0821	<i>Mm.</i> 0.0330	<i>Mm.</i> 0.0268	<i>Mm.</i> 0.0839	<i>Mm.</i> 0.0196
2.....	.660	.325	.193	.0939	.0839	.0321	.0277	.0889	.0193
3.....	.541	.300	.186			.0306	.0279	.0973	
4.....	.555	.284						.0919	

¹ Individual 1, just before molting into nymph; individuals 2 to 4, very shortly after molting into prenympths.

The prenympth molts into the nymph or pupa. The pupa is the longest of all forms of the insect and is easily discernible on the root by the presence of wing pads, even just after it has molted from the prenympthal form, and has a greenish color. Immediately after the skin is shed, these wing pads are yellow, but very quickly they become gray or blackish. During the first few days of the nymphal instar the insect is green or greenish yellow, and the compound eyes are indiscernible, but as it grows it lengthens, becomes constricted in the region of the metathorax, and turns orange, the mesothorax, however, remaining paler than the rest of the body. The compound

eyes show their red pigment and soon become prominent. Legs and antennæ are relatively long, and the femora exceed the tibiæ in length. At all times the rows of tubercular areas on the dorsum are well marked. During the nymphal instar the insect shows a very considerable growth; the newly molted individuals are quite flat, but full-grown nymphs are roughly cylindrical.

DESCRIPTION OF STAGES.

The nymph or pupa, full grown.

PL. XI; text fig. 9, p. 85.

General color orange or orange yellow; anterior part of mesothorax and mesosternum whitish, or at least always noticeably paler than the rest of body. Antennæ pale yellow, extended but little beyond anterior margin of prothorax. Compound eyes and ocelli dark red; former composed of large number of facets. Head and abdomen bearing 4, thorax 6 longitudinal rows of dark tubercular areas (coarse roughening of epidermis), each surmounted by a spine; wing pads dark gray, grayish black, or rarely jet black; legs pale yellow, often with a dusky cast; abdomen with 7 visible segments, mesothorax apparently bisected by a transverse fold; beak very pale yellow, reaching to posterior coxæ.

Measurements of 6 individuals are given in Table XXV.

TABLE XXV.—*Measurements of nymph of the grape phylloxera, Walnut Creek, Calif.*

Individual No. ¹	Length of body.	Maximum width of body.	Length of beak.	Length of hind femur.	Length of hind tibia.	Length of antennal joints.			Length of sensorium.
						1	2	3	
	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>	<i>Mm.</i>
1.....	1.102	.....	0.3295	0.1500	0.1366	.....	0.0402	0.1536	0.0223
2.....	.889	.....	.3600	.1464	.1384	0.0339	.0350	.1545	.0224
3.....	.957	.507	.3339	.1419	.1321	.....	.0331	.1455	.0230
4.....	.....	.....	.....	.1438	.1304	.....	.0332	.1455	.0254
5.....	.851	.....	.....	.1089	.1071	.0321	.0339	.1179	.0223
6.....	.798	.511	.....	.....	.....	.0304	.0295	.1184	.0232
7.....	.725	.....	.....	.....	.....	.....	.....	.....	.....
8.....	1.121	.558	.....	.....	.....	.....	.....	.....	.....
.....	1.197	.569	.....	.....	.....	.....	.....	.....	.....

¹ Individuals 1, 7, and 8 at end of stage; 4, 5, and 6 at beginning of stage; 2 and 3 about middle of stage.

Newly molted nymphs average about 0.78 mm. in length and mature nymphs about 1.1 mm. The nymphs are always more active than the immature wingless forms, wandering larvæ excepted. Their eyes are well developed, as in the winged insect, and they have the ocelli found in that form. The third joint of the antennæ bears a single sensorium corresponding to the apical one of the migrant, and as the last molt approaches the migrant antennæ show through the nymphal skin, and thus the nymphal antennæ appear to bear two sensoria.

The adult instar of the winged form shows what is probably the most highly developed form structurally of the phylloxera. The winged insect is, on the average, slightly shorter than the full-grown nymph. The antennæ are longer than those of the previous instar and bear two sensoria of about equal size. The comparatively large wings are weakly veined but necessitate strong muscles in the interior of the thorax. The legs are quite long and the tibiæ exceed the femora in length. As the migrant sheds the nymphal skin, pushing it back and moving about its appendages, the wing pads appear as little white rolls; the mesothorax is shining green, the head and abdomen bright orange. The wings unroll as the skin is being passed off the abdomen. As soon as it is entirely shed the insect moves off and then pauses while the wings assume their final shape and position, but remain whitish, hyaline, and limp. Soon, however, the wings dry and the thorax hardens and darkens until it is almost black. The head, prothorax, and abdomen remain orange, the head with a grayish luster. The molting process occupies about 50 minutes.

The adult winged form.

PL. VIII, a-c.

General color orange or yellowish brown or gamboge yellow; head a little dusky on the anterior half, especially the cephalic margin (front); ocelli dark red; eyes brighter red than ocelli, compounded of many facets; ocular tubercle small; antennæ with three joints, not quite reaching the anterior margin of the mesothorax, pale yellow, with apical fourth of joint 3 dusky gray; third joint much the longest, considerably over twice as long as first two combined, somewhat constricted beyond the basal sensorium and at extreme base; posterior half of head, prothorax, and abdomen orange, yellowish brown, or gamboge.

Thoracic lobes, scutellar lobes, scutellum, and mesosternum dark gray or blackish; legs pale yellow, tarsi duskie; wing insertions, stigma, and veins gray (at first greenish); stigma equal in length to about one-fourth of wing.

First discoidal arising from subcosta not far from basal angle of stigma, stout, not attaining the wing margin by a space equal to one-fifth its length; second discoidal faint, arising from the first vein or discoidal a little before its center and almost reaching the wing margin at a point a little nearer to the apex of the third discoidal than to that of the first; third discoidal faint, arising from first vein close to its base and continuing with a double shallow curve almost to the wing apex (the basal half of this vein generally obsolete). Lower wings with the costal vein running parallel to the anterior margin for its whole length; cauda bluntly rounded, bearing a fringe of hairs; beak slender, pale yellow, and almost reaching to second coxæ; two longitudinal oval sensoria on the third antennal joint; basal sensorium situated at basal third of joint, apical sensorium close to apex of joint. Wings borne horizontally, apparently the positions interchangeable, the right pair sometimes overlapping the left and vice versa. Abdomen widest at second and third abdominal segments, where it is wider than the thorax, and about as long as head and thorax combined. Body about as high as wide, not at all flat.

Table XXVI gives the measurements from 8 individuals.

TABLE XXVI.—Measurements of the winged migrant of the grape phylloxera, Walnut Creek, Calif.

	1	2	3	4	5	6	7	8
	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.	Mm.
Length.....	1.101				0.906			0.900
Width (abd. seg. 3).....	.428				.317			.390
Width (thorax).....	.333				.309			
Antennal joints, length:								
1.....		0.0384	0.0375	0.0321	.0320	0.0393		
2.....		.0402	.0393	.0304	.0366	.0384		.033
3.....		.1902	.1809	.1777	.1741	.1946		.207
Antennal joint 3, base to apex of basal sensorium.....		.0562	.0634		.0536	.0589	0.063	
Antennal joint 3, length of basal sensorium.....		.0268	.0304	.0241	.0214	.0304	.0275	
Antennal joint 3, length of apical sensorium.....		.0286	.0269		.0250	.0277	.0297	
Hind femur, length.....		.1901	.1802	.1500	.1848			
Hind tibia, length.....		.2179	.2250	.1643	.2062			
Beak, length.....					.229			
Wing expanse.....							2.73	

The prenympchal instar is passed in three or four days, in the same time in which the corresponding instar of the wingless radicle is passed. The nymphal instar, however, is relatively longer than the corresponding instar in the wingless form, and it is because of this fact that the migrant takes longer to mature than does the contemporaneous wingless radicle. The nymphal or pupal instar occupies from 5 to 12 days, the average being about 8 days.

The nymphs take more food than does the corresponding wingless form, and after they have left a nodosity or tuberosity upon which they have been feeding, the lesion rapidly decays unless other individuals are settled upon it. The nymphs do not usually move much during their period of growth, but if disturbed they move quickly and display a negative phototropism when suddenly exposed to light. The newly molted nymphs, however, often wander about with apparent aimlessness. The full-grown nymphs just before molting ascend the roots, seeking the surface, and transform on the trunk or else find their way along the root until they come to a crack in the soil, and crawling up the sides of the crack transform near the surface. In glass section cages, wherein the glass plates did not fit very tightly to the soil, the nymphs were found sometimes crawling up to within 2 or 3 inches of the surface and sometimes transforming close by the roots as much as 17 inches below the soil surface, the resultant winged aphids being compelled to find their way to the surface. It was concluded that owing to the loosely fitted glass plates of the section cages, which allowed abnormal light to penetrate below the surface of the soil, the nymphs did not wait to ascend toward the surface, but transformed below, their transformation being governed by the strength of the light rays to which they were subjected. It may be said that these section cages measured 9 by 24 inches, outside measurement, and allowed of a thickness of half an

inch of soil, which was a silty loam mixed with heavier clay loam. In some half-darkened cages, containing potted vines, the nymphs were observed to ascend to the level of the soil surface to transform. On the other hand, occasional nymphs have been found to transform on the roots as much as several feet underground, and many of the resultant migrants failed to reach the surface of the soil.

HABITS OF WINGED MIGRANTS.

Occasionally it was noticed in the jars that migrants would thrust their beaks into the roots and appear to feed. While engaged thus they lower the head so as to allow the beak to penetrate the tissues of the root. This organ appears to issue from the mesosternum, because of the curvature of the sheath. The femora are kept horizontal, and the antennæ are usually in motion. While the insect is walking the antennæ are in motion. The migrants, so far as has been noted, never feed after they issue from the soil. At all times they exhibit strong positive phototropism. When placed in a room they seek to crawl toward windows, and their activity is greatly increased when placed in the direct sunlight. If placed in a petri dish in the sunlight, they travel very fast and often take to flight, and are capable of keeping up a walking gait for hours. If the surface upon which they are standing becomes heated, they quickly die. If a vine leaf or other shade-giving object is placed in the dish, the phylloxeræ will finally settle on the shady side of the object. In the vineyard most of the winged phylloxeræ were observed to issue from the soil by creeping up the stumps of the vine. On arriving at the surface many of them passed to the soil and crawled around aimlessly. Others crawled up the vine, and when they reached a point of vantage, such as the end of a cane, they spread and vibrated their wings, as though inviting the wind to bear them off. Finally they launched themselves into the air and if they struck a wind current were borne off. Often after spreading their wings once or twice they turned about and crawled down the stalk, and frequently when they launched themselves into the air no current of wind caught them, and they half fell and half flew to the ground in an oblique direction, but at other times they flew off strongly without the aid of the wind. The migrants are capable of traveling by flight and with the wind, as is evidenced by the experiments conducted with sticky papers. (See Diffusion of phylloxera, p. 100.) They have been taken on such papers at least 80 feet from the nearest infested vine, and undoubtedly they may travel much farther.

In order to ascertain whether the migrants returned to the soil by crawling down the stem of the vine, 26 migrants were placed on the upper foliage of a small American vine (9 inches in height), on

August 17, 1914. Around the base of the vine stem were placed sticky papers, and the stem was encircled with glue. The vine was kept indoors and was not exposed to wind currents. Six hours after the phylloxeræ were placed on the leaves, eight individuals were caught on the paper. After 24 hours, 17 winged phylloxeræ were on the paper and 3 dead on the leaves, none having been caught in the circle of glue on the stem. Thus the phylloxeræ had either flown or dropped down and none had descended the full length of the stalk. Since none of the individuals on the papers were over 4 inches from the stem it would appear that they dropped rather than flew from the vine.

On August 22, 1914, 34 winged phylloxeræ were placed on the foliage of a riparia vine, 12 inches in height. This vine was potted and sunk in the soil and exposed to field conditions. Around the base an area of sticky paper 30 by 36 inches was laid. After two days an examination of the paper showed on the leeward side eight winged phylloxeræ, occurring $16\frac{1}{2}$, $16\frac{1}{2}$, 16, 16, 12, 10, 6, and $1\frac{1}{2}$ inches, respectively, from the stem, and one winged phylloxera on the windward side 2 inches from the stem. The remaining 25 were not recovered, and probably flew off or were blown beyond the paper. The location in which this experiment took place was subjected to wind that blew from one direction only. It is obvious that the wind was a factor in the distribution of these phylloxeræ.

In the observations on the flying of the migrants it was found that individuals would fly both in the sunlight and in the shade, that very frequently they refused to launch themselves even in bright sunlight and in all varieties of wind currents, and that they appeared to take no definite direction in launching themselves. As a general rule, the winged forms fly more abundantly in the sunshine than in the shade, and they are the more active the hotter and drier are the conditions of their environment.

PRODUCTION AND RELATIVE ABUNDANCE OF MIGRANTS.

In 1911, in the course of rearing experiments conducted in the laboratory cellar, the first winged forms were secured on August 2. These had been raised on a heavily infested piece of vinifera root and were part of the third generation of that year. In five localities in central California nymphs were collected in vineyards from August 3 to 19 and, judging from observations made in years following, it is possible that nymphs had been developed earlier in that season. In the laboratory the production of migrants proceeded until the end of November, but in the latter half of October and in November only a few developed.

In 1912 no record was made of the earliest appearance of nymphs and migrants, but they were found abundantly on young potted

vines (mostly resistants and American nonresistants) during September and October, and some were reared in the cellar during August.

In 1913 the first nymph was observed, July 9, on the root of an American vine, and at about the same time others appeared on young resistant hybrids in pots. On the severed pieces of vinifera roots kept in jars in the cellar nymphs occurred as early as July 12, and on July 17 the first migrants appeared. This was the first year in which experiments were conducted with living vines in cages, and on these the earliest nymphs and migrants were reared on July 20 and 28, respectively. In the experimental vineyard (Zinfandel) migrants were first collected about August 1, but some nymphs were found on July 25 in a vineyard at Napa, Calif. In general, migrants continued to develop until November, but after the middle of October their production was scanty, and in the vineyard very few were found later than September.

In 1914 nymphs were first observed on June 16, both in the experimental vineyard at Walnut Creek and on roots kept in the cellar. On June 18 a migrant was reared from a nymph collected in the vineyard two days previously. On the roots of the vines growing in cages nymphs were reared June 23. Throughout July and August nymphs and migrants were abundant in the Zinfandel vineyard. In September the numbers fell off rapidly and none were found in October. In infested vines in pots migrants were secured in considerable numbers throughout August and September, but were much more scarce in October.

In 1915, in the material reared under cellar conditions, the first nymph was observed on June 14. The day following, a nymph occurred on the root of a young vine planted in a section cage. In the cages containing living vines, the first nymph was reared June 23, and in the experimental Zinfandel vineyard, nymphs were collected June 22 and evidently occurred as early as June 15. In the vineyard the production of migrants continued until the end of September, and was abundant from July 15 to the end of August. In the material in the cellar jars, abundant migrants were secured throughout the months of July, August, and September, and the production continued until November 8.

In summing up, it may be said that in California the period in which migrants are developed in vineyards extends from the middle of June until the end of October; that these forms appear in greatest abundance from the middle of July to the middle of September (the hottest time of the year); and that the production is very limited in June and October. In small vines in pots, especially if consistent irrigation is practiced, the October production of migrants

was frequently large. In the case of pieces of vine roots kept in a cellar, abnormal conditions of food, temperature, and humidity frequently arose.

The conditions which affect the relative abundance of migrants are the following: Variety of vine, vigor of vine, humidity, temperature, condition of roots, character of soil.

Resistant and certain American nonresistant vines normally bear the greatest proportion of migrants. These vines are the descendants of the wild grapevines which formed, and still form, the natural food plant of the phylloxera, and which were immune from serious injury by reason of the fact that there was produced each year a large percentage of migrants, while few or no wingless forms persisted on the vines after the winged forms had departed. The wingless radicle forms during the summer fed only upon the terminal rootlets, and when these decayed the vine was easily able to replace them without suffering injury of any consequence. The resistant vines of to-day, except in instances in which the roots have been supplied with poor or insufficient soil, as is noted below, do not support heavy and continued infestations of wingless phylloxera, and almost all the phylloxera born in summer and autumn develop wings and become migrants. It may be said here that experimenting with resistant vines grown in pots with soil unchanged for over a year is apt to give misleading results, for as the soil becomes poorer and insufficient for the increasing root system of the vine, fibrous rootlets become scarce, and an abnormal infestation of wingless phylloxera and a diminishing production of migrant phylloxera ensue, thus approaching the conditions normally found on vinifera vines. On vinifera vines and on many American nonresistants, such as Isabella, Catawba, and Champion, the production of winged migrants is never proportionately as large as that which occurs on resistants. Well-nourished resistant vines have been observed to rid themselves entirely of the phylloxera, the insects all departing as winged forms, and in all cases under normal conditions, if any wingless forms remain after the winged forms have all left, the number is very small. On vinifera vines the total nymphal production has been found to be over 33 per cent of the whole in season, although three-fourths of the individuals produced on fleshy surface rootlets and on nodosities have been observed to develop into migrants, and on succulent pieces of severed root cuttings as large a proportion has been reared.

In the vineyard the larger roots were rarely found to produce a number of migrants in excess of 25 per cent of the whole number of phylloxera simultaneously developed, and under unfavorable conditions extremely few and sometimes no migrants were produced.

Under average conditions the proportion on the larger roots was between 5 and 10 per cent. Regarding the American vines of non-resistant type, a considerable diversity in the production of nymphs has been observed. On some, like Moore's Early, this production may be proportionately very large, while on others, like Isabella and Catawba, it may be smaller than on viniferæ, as occurred in the experiments in caged and potted vines. Vines like Agawam, Lenoir, and Delaware, vinifera crosses, bore about the same proportion of nymphs as the viniferæ, but among the labrusca types (Isabella, Moore's Early, Concord, Champion) there was considerable variation.

On resistant vines, the nymphs are developed on the nodosities, but on viniferæ and American vines of nonresistant type they are also produced on other portions of the root system. On phylloxerated viniferæ, the most abundant production of nymphs occurs on the fleshy and fibrous surface rootlets frequently observable in the vineyard. These rootlets are sent out in May and June, and often become grossly infested with phylloxeræ in June and July. Toward the end of July, they decay or dry out, and after that nymphs are produced only on the larger roots and on nodosities deeper in the soil. On the larger roots relatively few nymphs are produced before August or after September.

Among viniferæ the more vigorous vines produce the greater proportionate numbers of winged forms. Badly stunted vines showing several years of phylloxeration produce comparatively few, while the recently attacked vines around the periphery of "spots" produce large quantities. Viniferæ vines in pots produce great numbers the first year of infestation, but if the soil is unchanged in the second and third years, as the vines become weakened, they produce fewer winged forms.

As far as has been observed, all varieties of viniferæ produce the same proportion of migrants.

It has been observed frequently that a humid environment stimulates the production of migrants and a dry one precludes it. This has been especially noticeable in the cases of young vines in pots and of the severed roots kept under cellar conditions. The late appearance of the migrants in the experimental vineyard in 1913 as compared with those of 1914 and 1915 was perhaps due to lack of moisture in the soil in summer. The spring of 1913 was exceptionally dry, and the ground became very dry by June, whereas in the two years following, moisture was conserved in the top soil until July. The total migrant development of 1913, however, although at first retarded, was finally just about as large as those of the succeeding years. To hold the severed pieces of roots, glass jars and dishes were used in the cellar, and it was found that in the summer and fall

a layer of wet sand placed in the bottom of the jar was conducive to the production of migrants. When moisture was applied periodically to filter papers, the production of migrants was greater the more frequent the applications.

What effect, if any, temperature has upon the production of migrants can not be shown except that they are produced during the hottest months of the year. Contrasting the hot summer of 1913 with the cooler one of 1914, it was found that the production was about equal each year.

Migrants are produced in greater numbers in soils which retain moisture than in those which dry out rapidly. Otherwise no further influence traceable to soil conditions has been noticed. Although the general behavior of phylloxera differs considerably in relation to different types of soil, as between these different types the production of migrants does not appear to change.

In the season 1914, 12 vinifera vines were growing in cages. These were inoculated in the spring, and six of them later treated throughout the summer and autumn with fertilizers applied in liquid form periodically. These fertilizers—nitrogen, potash, phosphoric acid, and magnesium—were combined in a normal fertilizer and also used in combinations in which one element was in marked excess. The fertilized vines produced noticeably larger nymphal infestations. In 1915 other potted vines were treated likewise, except that all the fertilizer was mixed with the soil at the time of planting, and the vines were not inoculated until a month later. In this series the number of nymphs was no greater or less on the fertilized vines than on the unfertilized.

Migrants formed part of radicle generations 2 to 5, those of the third generation being the most abundant. It was never observed that any of the first generation (direct progeny of the hibernants) became winged.

NYMPHICAL OR INTERMEDIATE FORMS.

The insects of the nymphical type are intermediate in form between the winged migrant and the wingless radicle. In their adult stage they vary largely. Grassi (11) has figured and described several individuals which represent stages in the variation. His specimens varied from a type which differed only from the radicle in the possession of two or three extra eye facets and in longer appendages to one which superficially resembled a nymph in that it had well-developed compound eyes and noticeable wing pads. This last type, however, upon close examination, differed from the nymph as follows: (1) The antennæ (fig. 8; compare with fig. 9, antenna of nymph) frequently bore two sensoria, as in the winged insect, but the basal sensorium was less developed than in that form; (2) the wing pads

were not hard and straight and parallel to the sides of the body, but bulged out and appeared rolled up and were soft, also sometimes containing the sensory organs peculiar to the wing of the winged forms; (3) there were no wing muscles in the interior of the thorax; and (4) the structure of the vaginal segment of the abdomen was more developed than in the nymph. From this it appeared that this type of nymphical was more comparable to the winged insect notwithstanding its superficial resemblance to the nymph, and this conclusion would be the more obvious when it is considered that the nymphical is an adult insect of the fifth stage.

In Italy the intermediates are said to be quite abundant among the nymphs in the season of the year (July to October) when the latter are being produced on the vines. They were found to be especially abundant on vines of the American type but also not uncommon on *viniferae*.

In California, in the year (1915) in which were carried on researches upon the intermediate forms, there was a very small available supply of infested American vines, and the observations were confined chiefly to *viniferae*. On the American vines such as were examined one nymphical was found.

In looking over a series of slides made in 1914, a single nymphical was recognized; the year following, during the nymphal season (June to November), frequent examinations were made on *vinifera* vines, and in all 15 intermediates were secured from these. The individual from the American vine (Wyoming Red) and nine of those on *viniferae* were recognized through the medium of mounting large numbers of insects and later examining them through the microscope. The remaining six were discovered on the roots through the use of a binocular microscope, and all of them had rudimentary wing pads, so that it is likely that others of the type lacking these pads were observed but not recognized as intermediates.

In the two years covering the investigation a total of 17 intermediates came under observation. None of these was found earlier in the year than the middle of September, and 12 were collected or observed between September 14 and 27, 1915, and 1 on September 10, 1914. Of the 4 remaining, 1 was observed on a piece of root October 14, 1915, and 3 others October 27, 1915, 1 of which was in the fourth stage and matured November 1. These 17 individuals differed greatly one from another and represented all the types discussed by Grassi and Foa. The types intergrade, and, in fact, no two of the examples were alike. For the sake of comparison, they may be divided into three arbitrary groups: (1) Those without vestige of wing pads; (2) those with small buttonlike wing pads not visible from above; (3) those with larger wing pads protruding (as in the nymphs, fig. 9) beyond the lateral margin of the body and there-

fore visible from above. In group 1 were two individuals collected on young vinifera vines. One of them greatly resembled an adult

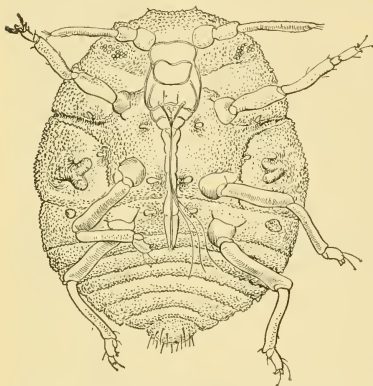


FIG. 6.—*Phylloxera vitifoliae*: Intermediate of type 2, ventral view. Much enlarged.

wingless radicle, but besides the larval eyes it had two to three extra facets, and the antennae and legs were longer than in the radicle. The other was slender, resembling a prenymph in shape, and had about six extra eye facets, and one antenna showed two sensoria. Group 2 (fig. 6) had six representatives, all with small to very small rudimentary wing pads invisible from above. In all cases the antennae (fig. 8) and legs were long, and one insect had two sensoria

on antennal segment III. In shape the individuals resembled wingless radicles. One specimen (from Wyoming Red) had no extra eye facets, and the others from young viniferae had a varying number, usually 10, although one had about 15. The remaining 9 individuals came under group 3 (fig. 7), and, because of their more pronounced nymphlike characters, these are more easily observed in life upon roots than are those of the other two groups, and 4 of the 6 individuals recognized alive on roots were of this type.

It is probable, judging from random collections, that the insects of groups 2 and 3 are about equally abundant and each somewhat more so than those of group 1. All the individuals of group 3 had rudimentary wing pads, in many cases almost as large as the wing pads of the nymphs. They bulged out from the sides of the insects, and were soft and appeared coiled (fig. 7) or curled. The compound eyes were well developed, there being from 66 to 100 per cent as many facets as in the nymphal eyes. In some cases the larval

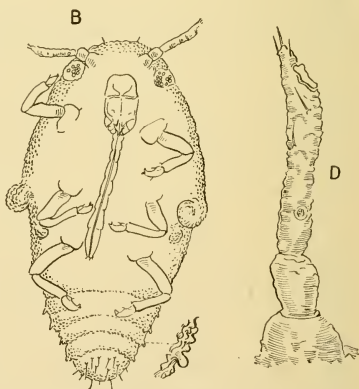


FIG. 7.—*Phylloxera vitifoliae*: Intermediate of type 3, ventral view, much enlarged; antenna at right, more enlarged.

eyes were absent, and in no case were ocelli discernible. In most individuals there were two sensoria on the last antennal joint, and in one antenna there were two small basal sensoria and the usual apical sensorium, making three in all. The basal sensoria were not in any case as large as those of the winged migrant. The antennæ and legs were about as long as those of the nymph, noticeably longer on the average than those of the individuals of group 2, which in turn were longer than those of the two individuals of group 1.¹⁰ It would appear, therefore, that greater development of wing pads and compound eyes is complemented with a lengthening of legs and antennæ and a tendency to bear the extra sensorium of the winged forms. The femora exceed the tibiæ in length.

There is among the intermediates a tendency toward asymmetry. This was remarked in Italy and has also appeared in California.

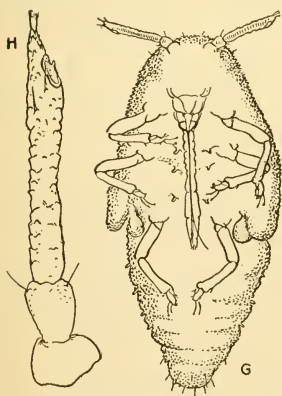


FIG. 9.—*Phylloxera vitifoliae*: Nymph and antenna of newly molted insect, for comparison with intermediates.

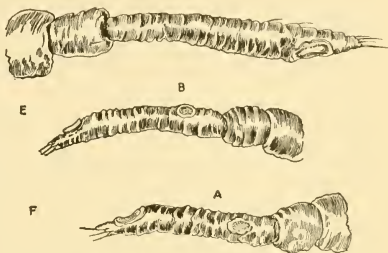


FIG. 8.—*Phylloxera vitifoliae*: Types of antennæ of intermediates. Greatly enlarged.

One eye may have more facets than the other; the lengths of antennæ and legs may differ in individuals, those of one side being longer than their counterparts, and one antenna may possess more sensoria than the other.

In two instances the fourth stage of intermediates was observed in California. In one case an individual of group 3 molted from what appeared, under the lenses of the binocular microscope, to be a true nymph. In the other case an example of the same group molted from an insect which itself resembled a nymphal; in fact, after the molt the individual did not appear to have changed its structure at all. In both fourth and fifth instars the wing pads were large and "fleshy."

From three individuals, all of group 3, eggs were obtained. These eggs could not be differentiated from eggs laid by wingless radicles. One nymphal deposited two eggs, which were lost. An-

¹⁰ The insect depicted in figure 7 is considerably less enlarged than that represented in figure 6.

other deposited two eggs, on September 28 and 29, respectively. These hatched in 11 days, the resultant larvæ obviously being radicoles but surviving only a few days. The third individual matured November 1, and between this date and November 10 it deposited 10 eggs. After this it became weak, and on November 16 was mounted on a slide. The eggs were exactly similar to those laid by wingless radicoles, and two of them measured, respectively, 0.310 by 0.166 mm. and 0.297 by 0.168 mm. Seven eggs were transferred for observation to another root, and three eggs hatched in from 14 to 16 days, the resultant larvæ settling down for hibernation. One of these soon died, but the other two passed the winter in due form, and matured in April, 1916. Both of them were typical radicoles and subsequently deposited many eggs.

In Italy Grassi and his assistants found that the great majority of the intermediates were parthenogenetic, but one individual was found to contain a sexed egg. In discussing the phenomenon of the intermediates, they gave it as their opinion that the parthenogenetic individuals were those which up to their third stage were destined to become radicoles, but in that stage changed their development to that of winged migrants, while the character of their eggs had been already fixed before the change and so remained parthenogenetic. In the case of sexuparous intermediates the change was made in the reverse direction, the larvæ at first being destined to become migrants and, therefore, when they matured as nymphicals they deposited sexed eggs.

In California the recorded eggs laid by nymphicals were all parthenogenetic, but the possibility of some of such eggs being sexual is not entirely excluded, in the writers' opinion.

The nymphicals do not leave the roots in the manner of the winged insects, and therefore deposit their ova on the roots. In the case of sexuparous nymphicals, the sexes and winter egg would presumably develop underground. Whether in California such a development occurs or not can not be stated from our present knowledge, but in view of the fact that for many years the leaf galls have been unknown, it appears certain that such a cycle proceeds no further than the winter egg.

DEPOSITION OF THE SEXUAL EGGS.

The migrants deposit eggs (Pl. VIII, *f*, *h*, *i*) which are of two kinds, viz, male and female, and from these eggs issue the true sexual aphids. Sexual eggs have never been found by the writers in the vineyard, either on viniferæ or on resistant vines, although a large number of vines have been examined. In laboratory experiments a large number of sexed eggs have been produced. Considerable discussion has taken place among European writers as to the normal

location of the sexed eggs. Taking the sum of these discussions, it appears that they are placed on the underside of the leaves and more abundantly in the bark, generally between the year-old layer and that of the current year, and are fastened to the inner side of the former. Occasionally eggs are found at the base of canes where the new wood joins the old, and rarely on the vine supports (stakes). They are laid on both viniferae and resistant vines, but preferably on the latter.

Observations were conducted in small cages, and in a few instances on living vines in pots. In the latter instances eggs were found laid on both the foliage and bark. Many different kinds of cages were used and experiments with different degrees of light, moisture, and temperature were conducted. Vine leaves and pieces of bark were inclosed in the cages. As a rule, the migrants, though primarily attracted to light, deposited their eggs in semidarkness. They laid them on the leaves and more rarely on pieces of bark offered, but often also on the sides, lid, and floor of the cages and in cracks. In 1911 the observations tabulated in Table XXVII occurred.

TABLE XXVII.—*Sexual production of the grape phylloxera, Walnut Creek, Calif., 1911.*

Number of migrants.	Date and location of migrants.	Number of sexual eggs deposited. ¹	Date of deposition.	Date of maturing of sexes.	Number of sexes matured. ²
25	Aug. 4-6: Riparia vine in pot.....	16	Aug. 9	.....	.....
52	Aug. 7-8: Vinifera vine in pot.....	0	.....	.....	.....
65	Aug. 10-12: Riparia vine in pot.....	18	Aug. 16	Aug. 26	4
				Aug. 28	1
80	Aug. 13, 14: Vinifera vine in pot.....	2	Aug. 15	Aug. 30	1
		1	Aug. 20	.....	0
25	Aug. 15: Riparia vine in pot.....	2	..do.	.....	0
36	Aug. 16: Riparia vine in pot.....	5	..do.	.....	0
30	Aug. 17: Glass tube in drawer.....	0	.....	.....	.....
83	Aug. 18, 19: Riparia leaves in petri dish.....	7	Aug. 21	Sept. 6	1
		5	Aug. 22	.....	0
		12	Aug. 23	.....	0
1	Aug. 19: Leaves in petri dish.....	1	Aug. 19	Aug. 30	1
?	Aug. 23: Leaves in petri dish.....	7	Aug. 23	Sept. 2	1
69	Aug. 24: Riparia leaves in laboratory.....	1	Aug. 25	.....	0
		1	Aug. 26	.....	0
		1	Aug. 27	.....	0
		8	Aug. 28	.....	0
		1	Aug. 29	.....	0
30	Aug. 25, 26: Riparia leaves in petri dish.....	1	Aug. 27	.....	0
		6	Aug. 28	.....	0
		1	Aug. 30	.....	0
45	Aug. 25, 28, 29: Riparia leaves in petri dish.....	7	Sept. 3	.....	0
103	Sept. 2-17: Vinifera vine in pot.....	30	Sept. 25	Oct. 4	1
				Oct. 5	2
				Oct. 6	0
50	Sept. 19-23: Riparia vine in pot.....	6	Sept. 29	.....	0
40	Sept. 25-29: Riparia vine in pot.....	0	.....	.....	.....

¹ Thirteen female and three male eggs.

² All maturing sexuals were females.

TABLE XXVIII.—*Summary of Table XXVII.*

Number of migrants.....	734
Number of sexual eggs deposited.....	171
Number of sexual eggs hatched.....	13

Individual egg deposition by migrants, recorded for 5 individuals, was as follows: 3, 2, 1, 4, and 3; average, 2.6. Obviously the great majority of migrants died without depositing eggs. The eggs above recorded were laid in from 2 to 9 days, the majority in from 3 to 5 days, after the migrants emerged from the nymphal skin. The great majority of the migrants did not live more than 3 days after casting their final molt, confinement evidently having caused premature death.

From 100 migrants produced August 15, 1912, and placed on a small vine August 20, a single egg, which failed to develop, was deposited August 24.

In 1913 different types of cages were utilized in an effort to induce a larger percentage of eggs and mature sexuals. The results were not encouraging. From July 17 to October 17 migrants were placed in the cages. During that time in some 60 experiments, 317 migrants were used, 99 sexual eggs were secured, and 7 sexed phyloxerae (all females) matured. The migrants in no case lived more than 6 days, the majority only 3 days, and quite a number did not move their position after having been placed in the cages. In most cases eggs were laid singly, but there was one group of 5, three groups of 4, and several of 3 and 2, laid by single phyloxerae. In two cases eggs, presumably of separate sexes, were deposited in the same group by the same individual, but in all other cases it appeared certain that the eggs laid by individual migrants were of only the one sex. Judging from the size, about twice as many female as male eggs were laid, besides quite a number (about 20 per cent) of eggs of an intermediate size. No male or intermediate sized eggs hatched, but it was noticed that the male eggs, as they developed, assumed a darker color than did those of the female. After a certain point in the development, all the moribund eggs began noticeably to shrink and turn dark brown. None of the eggs showed signs of infertility, and within about five days of deposition hatching occurred and the eyes and body segmentation were visible, after which the moribund individuals discolored and shrank rapidly. Dead migrants were found occasionally on the roots and sides of the cellar jars, beside eggs that they had deposited. In the vineyard such a procedure was never observed, and therefore it is believed to be quite abnormal, and probably results from the inability of the migrant to escape from the cellar jar after having been overlooked in the periodical examinations for migrants.

During the summer of 1914 a further series of experiments on the production of sexual eggs took place. The temperature that year was considerably below that obtaining in the years 1911 and 1913, and this may account for the lack of sexuals maturing. In 1914 the cages utilized in 1913 and some of other types were employed.

The experiments began June 27 and terminated September 7. Three hundred and ninety-seven migrants produced a total of 143 eggs from which no sexual forms developed. Thus the proportion of deposited eggs to migrants in 1913 was 1 to 3.2, while in 1914 it was 1 to 2.75, and in 1911, 1 to 4.3. In 1914 four migrants each deposited four eggs, and three eggs were deposited in nine instances, but most of the eggs were laid singly. In no case could it be definitely said that eggs of more than one sex occurred in individual groups. About three times as many female eggs as male were deposited, and about one-fourth of the eggs were intermediate in size (probably males). The winged sexuparae died on the average two and one-half days after they were admitted to the cages, or about four days after they had transformed from the nymphal instar.

In 1915 experiments were continued, migrants being secured from June 26 to October 27. Part of these were used in stender and petri dishes, part in small circular rubber cells ($\frac{3}{16}$ inch high, $1\frac{1}{4}$ inches in diameter) mounted on microscope slides with cover glasses for lids, and a few on a living vine (*Riparia*). In the dishes small pieces of vine, bark, or leaves were placed, leaves of the Champini being used mostly on account of the fact that the migrants prefer to deposit eggs on a tomentous leaf. The effect of variations in temperature and humidity was noted.

A total of 1,961 migrants deposited in all 472 eggs, and 52 sexuals matured. Thus the proportion of eggs to migrants was approximately 1 to 4.15. In the stender and petri dishes and on the living vine combined, 938 migrants deposited 167 eggs, a proportion of 5.6 to 1, of which 16 sexuals matured. In the rubber cells mounted on microscope slides, 1,023 migrants deposited 305 eggs, a proportion of 3.3 to 1, and 36 sexed forms matured. The rubber cells therefore gave a greater proportion of eggs per migrant. Part of these cells were kept in a cellar and part inside a slide box in a room of the laboratory. The egg deposition was not appreciably different in these two situations, but the sexes under the almost constant temperatures of the cellar matured better than under the fluctuating temperatures of the room. Part of the dishes also were kept in the cellar and part exposed to light in the room. Those in the latter situation averaged more eggs per migrant, but the proportion of sexes which subsequently matured was similar to that of the migrants and dissimilar to that of the eggs.

It appeared at first that exposure to light induced the migrants to deposit a greater proportion of eggs and later appeared to have prevented a large proportion from maturing. Judging from the fact that the amount of light to which these eggs were subjected during their development was not greater than occurs under natural conditions, however, it would appear that this supposition is incor-

rect and that the disproportionate mortality among the eggs was caused rather by the uneven temperatures prevailing in the room. The presence or absence of humidity had no apparent effect on the deposition of eggs. Eggs and sexed forms developed better in dry than in moist rubber cells, but in the dishes exposed to light the converse occurred. Part of the migrants were stimulated to fly in the sunshine before being placed in the cages, and deposited a somewhat larger average number of eggs than those which had not flown, but the flight or nonflight of the migrants did not appear to influence the subsequent development of the eggs and sexes. In July and the first half of August, when the temperatures reached a maximum, there was a higher average in egg production and in the proportion of sexuals matured, yet during the period September 16 to October 27, despite lower temperatures, a larger average proportion of eggs per migrant and of mature sexes was produced than during the intermediate period from August 16 to September 15.

On the whole, development was most successful where migrants had flown and when eggs were kept in moderate light and in a moderately humid environment.

The longevity of the migrants, the number of eggs deposited per individual, and the proportion of male and female eggs laid coincided with the results of experiments in 1914.

It is only necessary to consider the very small proportion of eggs laid per migrant (in 1915, for instance, 1 to 4.15) and the very small proportion of eggs which succeeded in developing into mature sexes (in 1915, 1 in every 9) under artificial conditions to realize how abnormal these conditions must have been. From observations made in California during 1915 the complement of migrant eggs was found to average 2.6, so that if all the migrants in the experiments in that year had deposited their full complement, ten times as many eggs as were actually deposited would have been obtained. European experimenters have had, for the most part, similar results in their study of migrants in confinement.

In not a single instance was a migrant observed to deposit other than a sexual egg, so the possibility of the occurrence in California of a parthenoparous winged form may be regarded as excluded. There occurs, however, a parthenoparous nymphical form, which has been discussed above (p. 82).

THE SEXUAL FORMS.

The sexual forms (Pl. VIII, *j-m*), male and female, issue from eggs deposited by the winged sexuparæ or migrants. These eggs are of two types, male (Pl. VIII, *f*) and female (Pl. VIII, *h, i*). Writers have attempted to recognize a third type intermediate in size

between the larger female and the smaller male egg, but these intermediate eggs are apparently always of the male sex. Thus there is a considerable variation in the dimensions of the male eggs, as, indeed, there is in those of the mature male insects. According to Grassi (11, p. 134-135) eggs producing females vary in length from 0.384 to 0.323 mm., and in width from 0.176 to 0.164 mm.; eggs producing males, in length from 0.247 to 0.250 mm., and in width from 0.152 to 0.134 mm. He also states that eggs of the intermediate dimensions are fertile and are of the male sex, and that male and female eggs may exceed the limits in one dimension, but never in two. On the average the female eggs were slightly larger than the radicle eggs and the male eggs slightly smaller, but intermediate eggs had measurements identical with those of the radicle eggs.

Measurements of sexual eggs, made in California in 1913, indicated a range in length from 0.450 to 0.257 mm., and in width from 0.171 to 0.117 mm. A single female of these hatched (0.357 by 0.171 mm.). In the light of measurements made in 1914 and 1915 it appeared that eggs of the sexes were similar in dimensions to those recorded by Grassi for Italy, except that the range in sizes was somewhat greater.

The sexual eggs are bright shining yellow. The eggshell is very thin and membranous, quite differently formed from that of the radicle. The egg hatches after about four or five days' incubation, the process of hatching consisting in the sloughing off of the thin shell, the emerging aphid settling at the place of hatching. The eyes and body segmentation become visible, and the undeveloped appendages are carried under the body. The insect then undergoes four successive molts, and does not move away until it is mature. During the first three instars there appears but little change, except that the body segmentation becomes more distinct. After the third molt the appendages project slightly beyond the sides of the body, but otherwise no visible change occurs. All the molted skins are contained one within another, adhering to the posterior end of the body, and when the last molt has taken place the adult moves away, leaving the "nest" of telescoped skins and eggshell behind. It sometimes happens that the adult is unable to cast off this pad of skins. The mature sexuals are capable of running actively, and, according to European investigations, they may live for some weeks, thereby facilitating a meeting of the sexes. The sexuals take no nourishment. The female is slightly larger and the male slightly smaller than the newly hatched radicle.

DESCRIPTION.

THE SEXUAL FEMALE.

Orange or orange yellow; antennæ and legs dusky grayish; antennæ longer than those of newly hatched radicle. Body a little longer and wider than

the young radicle. Caudal segment bluntly rounded. Eyes as in the radicle larva. When the adult issues the single egg within is small, but within three days it becomes very evident (Pl. VIII, *j*) and occupies in section an area equal to about three-fourths of the entire insect.

TABLE XXIX.—*Measurements of mature sexual females of the grape phylloxera.*

	1	2
	<i>Mm.</i>	<i>Mm.</i>
Length of body.....	0.357	0.464
Maximum width of body.....	.200	.215
Length of "winter" egg contained.....	.313	.....
Maximum width of "winter" egg contained.....	.172	.....
Antennal joint 1, right, length.....	.017	.0200
Antennal joint 1, left, length.....	.016	.0179
Antennal joint 2, right, length.....	.013	.0205
Antennal joint 2, left, length.....	.013	.0188
Antennal joint 3, right, length.....	.054	.0580
Antennal joint 3, left, length.....	.053	.0553

THE MALE.

Dusky orange, darker than the sexed female; antennæ, legs, and genital segment dusky grayish; eyes of three facets each, red; beak absent. Body quite noticeably shorter, flatter, and narrower than that of the sexed female, and shorter and narrower than that of the newly hatched radicle. Genital organ acutely conical.

TABLE XXX.—*Measurements of mature males of the grape phylloxera.*

	1	2
	<i>Mm.</i>	<i>Mm.</i>
Length of body.....	0.260	0.334
Maximum width of body.....	.094	.154
Antennal joint 1, length.....	.013	.....
Antennal joint 2, length.....	.018	.....
Antennal joint 3, length.....	.065	.071
Hind tibia, length.....	.046	.....
Hind femur, length.....	.056	.....

In confinement both sexes at first exhibit a positive phototropism, but after a day of maturity they seek shaded places. At first they are quite active, but later become sluggish. Undoubtedly they are much less active in confinement than in the natural state.

Table XXXI summarizes the development of the sexed form in the summer and fall of 1911 and 1913. All those which reached the adult state were females.

TABLE XXXI.—*Summarized record of sex development of the grape phylloxera, Walnut Creek, Calif., 1911 and 1913.*

	Number of individuals.	Days.
Average incubation period.....	12	5
Average postembryonic period.....	12	5.83
Average period of development.....	20	11.05

TABLE XXXIII.—*Summary of Table XXXII.*

	Days.
Maximum developmental period.....	21
Minimum developmental period.....	9
Average developmental period.....	12.73
Average developmental period, female.....	12.65
Average developmental period, male.....	13.10

During the developmental period preceding September the sexes developed in an average of 11.1 days, and in the remaining period, from September 1 to November 3, in 16.1 days.

The males appeared to develop more slowly than the females, but a larger series might not indicate such a difference.

The sexes, as soon as mature, were confined in a microscope-slide cell with a piece of vine bark and some filter paper. None lived more than three days, and copulation was observed in several instances, but on the whole the sexuals showed little activity and were not much attracted to each other. Several of the females partly extruded a winter egg, but chose no especial locality for oviposition, and their action was undoubtedly abnormal.

Mating is said to occur normally on the bark of the vine, the female depositing a single egg under and between the layers of bark. The egg is attached by a curved peduncle generally to the inner surface of the 2-year-old bark, but sometimes to older layers.

The Italian investigators found that eggs were most abundant about midway between the base and head of the vine trunk, but that they might be deposited on any wood of 2 or more years of age as well as on buds. The egg at first is greenish yellow, and later becomes greenish brown, remaining so until the time for hatching in the spring following. The phylloxeræ issuing from the winter egg are said always to become the gallicole (gall-inhabiting) stem mothers.

At Walnut Creek all types of vines exposed to phylloxera infestation have been searched exhaustively without more than a single winter egg being found. Among these vines were included viniferæ taken from phylloxerated vineyards, and viniferæ and American experimental vines grown in pots and boxes. The single egg brought to light was observed in December, 1912, located under the outside layer of bark of a young potted vine (Champenal). This egg, after having been kept under observation for three weeks, died.

From all observations in California it appears that conditions are unfavorable for the successful development of the sexual phylloxeræ and, therefore, for the "winter" egg and succeeding generations of gallicoles. Since in some parts of France a similar condition in the phylloxera cycle obtains, it was concluded that some factor was lacking to insure successful development, and there was reason to believe that humidity was one of the factors until the discovery of

the existence of the gallicoles in Arizona under dry climatic conditions appeared to disprove this theory. At present it is held that the phylloxera in California is undergoing, and since it was first introduced (about 60 years ago) has continuously undergone, a marked change in habits resulting from variations in the character of its food. Wherever the phylloxera is attacking vinifera vines its habits are undergoing change. In many localities the production of sexuals, winter eggs, and gallicoles proceeds simultaneously with prolific agamous radicicole infestation, and in such places speedy diffusion of the species obtains by reason of the winged insects and gallicole in addition to the wanderers. In California and in certain other localities the spread of the phylloxera has been slow, primarily because the danger from the agencies of the migrants and gall inhabitants has been very slight, and this notwithstanding the presence of resistant vines, the type on which the gallicoles normally form the galls and on which the "winter" eggs develop the more successfully. Thus it appears that the phylloxera, since it has been in California, has modified its habits to suit its environment, by exchanging the complicated life cycle on its native plants (native vines of eastern North America) for the more simplified life cycle upon *Vitis vinifera*.

THE GALLICOLE AND ITS RELATION TO CALIFORNIA CONDITIONS.

In the eastern United States, in Arizona, and in the majority of the phylloxera districts in Europe the gall form or gallicole occurs. This is most prevalent in the more humid districts, and occurs chiefly on American vines and American hybrids and only rarely on *Vitis vinifera* and its hybrids. Recent research in European countries, especially in Italy by Grassi and his colleagues, has proved that the original gallicole hatches from the winter egg deposited during the previous autumn by the sexed female in a crevice in the bark. This larva hatches with the appearance of the first leaves and attaches itself to the surface of a young leaf, where its punctures produce a "pocket" formation in the leaf tissue. In this pocket it grows, matures, and deposits its eggs. Upon hatching, the resultant larvæ seek young leaves higher up on the growing cane, and, settling on the surface, cause further pocket formations. Succeeding generations follow throughout the summer, the numbers being more and more reduced by predacious enemies (Syrphidae, Agromyzidae, Coccinellidae, etc.), and also by a certain percentage of the newly hatched larvæ deserting the cane for the roots. Among the later generations the percentage of larvæ that seek subterranean existence increases, and such larvæ may be differentiated by certain characteristics, when newly hatched, from those destined to continue on the foliage. They possess relatively longer beaks and a different anten-

nal structure, including relatively larger sensoria. To these small larvæ has been given the name *neogallicola-radicicola* (young gall lice with root louse characteristics), while to the type which merely moves from one leaf to another younger one has been given the name *neogallicola-gallicola* (young gall lice with gall louse characteristics).

On the European vine (*Vitis vinifera*), according to Grassi, winter eggs were rarely laid and galls rarely found, the majority of those found being imperfect. It was apparent also that growth was much slower than on American vine foliage. In Italy, from eggs produced by nine gallicoles that had produced galls on a European vine, a few of the progeny had radicolle characteristics. This, however, was a rare occurrence, the great majority of young larvæ hatching in galls on European vines showing the gallicole characteristics and thus not being destined for subterranean life. The Italian investigators were able to cause radicolles to settle and produce generations of gallicoles on the leaves of a Clinton (American) vine. This succeeded after several fruitless efforts. In this connection it may be said that, at Walnut Creek, on a small Golden Champion (American) vine, radicolles ascending the stalk and ovipositing in crotches of the stem as high as 5 inches above the surface of the soil were observed in the fall of 1914. A few of the resulting larvæ settled still higher up on petioles. Finally cold weather in November ended this aerial infestation either by killing the larvæ or compelling them to descend below ground.

On July 16, 1913, a shipment of eight leaves of an American vine well infested with gallicoles was received from Vienna, Va. The gallicoles were egg-laying females, probably of the second generation (progeny of stem mothers), newly hatched larvæ, and large numbers of eggs. Only one adult occurred in each gall. Four of these leaves were placed contiguous to foliage of three resistant vines. The varieties were Riparia $\times$ Rupestris 3309, Columbaud $\times$ Riparia, and Solonis $\times$ Riparia. The first two named, small vines in pots, each were inoculated with one infested leaf; the third vine, larger and growing in the vineyard, was inoculated with two leaves. In no case were galls developed on the foliage of the three vines inoculated. It is to be recorded that these three vines were of a different type from the infested vine, but the Riparia type is susceptible to gallicole infestation.

On September 6, 1913, a selection of foliage of a Riparia hybrid infested with gallicoles was received from Washington, D. C. The following vines growing in the vineyard were inoculated with the infested foliage in close contiguity: Riparia $\times$ Rupestris 3309, Rupestris St. George, Rupestris $\times$ Berlandieri 301 A, Berlandieri $\times$ Riparia 34 E. M., Riparia $\times$ Cordifolia $\times$ Rupestris 111-8, Riparia

Gloire de Montpellier. The infested foliage had an abundant supply of newly hatched larvæ, but in no case did the inoculation succeed. It is possible, however, that many of the larvæ of such a late generation had radicle characteristics, and therefore none such would settle on the leaves. Both of the foregoing series of inoculations were made under conditions of light atmospheric humidity. Recent research in Italy (11, p. 335-345) (17) shows that in that country, at least, humidity and irrigation have much influence in the production of galls on resistant vines. Both the *Riparia* × *Rupestris* 3309, and the *Rupestris* St. George are said by Panatelli to produce many galls in dry locations. It appears, however, that in general a greater humidity is conducive to the production of gallicoles on resistant vines and their hybrids. Thus out of 24 well-known resistant varieties enumerated by Panatelli, 21 produced many galls and 3 few galls in humid localities, while in dry locations 10 produced no galls, 5 few galls, and 9 many galls (17). In this connection, it may be added that in California resistant vines have been frequently observed growing among badly infested viniferæ and never showing any sign of gall infestation. On no occasion, indeed, have the writers ever observed phylloxera galls in California, and there is only one authenticated case in California of gallicoles, that being the discovery in August, 1884, by Dr. F. W. Morse (16), of gall-inhabiting phylloxeræ on a Canada (*labrusca* × *riparia* × *vinifera*) vine on the University of California grounds at Berkeley.

The two shipments of gallicoles cited above were also used in experiments to determine whether this form would live on roots. On July 16, 1913, 75 newly hatched gallicoles were placed on two pieces of severed root (*Zinfandel*) in a petri dish in the cellar. On a third smaller root 100 eggs from the galls were located. On August 18, on the two larger roots, five phylloxeræ with the typical radicle characteristics matured. On September 3 there were altogether seven mature egg-laying radicoles, of which six had matured on the two larger roots. Thus out of 100 eggs and 75 newly hatched larvæ only seven phylloxeræ matured.

On September 6 a similar experiment was begun on severed roots in the cellar. On two roots 75 eggs apiece were placed. These all turned black and none hatched, it appearing that the embryo suffered injury through fermentation that developed during the transcontinental journey. This supposed fermentation did not affect the larvæ already hatched and which were used for the foliage experiment.

A further experiment took place on roots of a living vine (Thompson's Seedless) which was inoculated July 16 with 50 eggs. Three insects from this inoculation matured August 12, 13, and 14. They were typical radicoles and laid eggs at the rate of between two and

three daily, at first exceeding that number. These eggs were typical radicle eggs, and produced further radicle generations. Twelve of the eggs laid August 21-24 were transferred to another root of the same vine (Thompson's Seedless) and four insects matured between September 28 and October 5, after an average egg stage of about seven and one-half days and an average growing period of 35 days. The progeny of these four became hibernants, several of which matured and oviposited the following spring. These experiments demonstrate that under California conditions it is possible for larvæ hatching in galls to mature on the roots and become typical radicle eggs. No observations were noted regarding the characteristics of the newly hatched gallicoles used in the experiments. After the inoculation, July 16, of 50 eggs on the root of the living vine it was seen that most of these eggs turned dark brown and failed to hatch. The observations on the hatching of this batch of eggs indicate that those failing to hatch were the earliest deposited, and it may be that the change in conditions and environment affected the embryonic development adversely.

The present nonappearance in California of the gallicole and its work on the foliage of grapevines, a condition paralleled in certain portions of Europe, vitally affects the entire biology of the insect, since it has been ascertained that the phylloxera issuing from the winter egg can only exist on the leaf or petiole as a gallicole. The Italian investigators Grassi, Topi, Grandori, and Foa found that no larvæ hatching from winter eggs fastened on the roots and that all of this generation of stem mothers (fundatrices) had the gallicole characteristics. This is a very important biological point. It is borne out by observations in those parts of Europe where the gall form is absent and in which winter eggs are extremely rare. It is similarly borne out in the phylloxera regions of California, where similar conditions occur. During the winters of 1912-13 and 1913-14, an extensive series of vines, large and small, of all types, many of which had been infested the previous summer with winged phylloxera, and others which, while themselves uninfested, had been growing near such infested vines, were examined. With only one exception, no trace of winter eggs or dead sexuals was found. This exception consisted in the single winter egg noted under the preceding heading.

EFFECTS OF WATER AND HEAT ON PHYLLOXERA.

Experiments were carried out to determine (1) the resistance of hibernant larvæ and eggs to water heated to various temperatures, (2) the resistance of hibernant larvæ to submersion in water at ordinary temperatures, and (3) the resistance of eggs to the heat of the sun.

During the winter of 1913-14, two experiments were made on the resistance of hibernants to hot water. The temperatures used ranged from 116° to 137° F., and the duration of submergence ranged from one to four minutes. A temperature of 120° F. failed to destroy the aphids completely, while 125° F. with a submergence of one minute destroyed all the insects. Similar treatment of the roots of living vines resulted in no appreciable injury to dormant plants.

The same winter, between December 3 and March 17, a series of nine experiments were carried out bearing upon the resistance of hibernant larvæ to submersion in water of ordinary temperatures. Pieces of heavily infested grape roots were placed in petri dishes under about 1 inch of water. The periods of submersion ranged from 48 hours (two days) to 1,512 hours (nine weeks). It was found that with the lengthening of the submersion period the percentage of aphids succumbing increased. A submersion of six weeks, however, resulted in the destruction of only 72 per cent of the aphids, one of five weeks in 64 per cent mortality, the final test (that of nine weeks) alone destroying all the aphids. In tests of from 48 to 168 hours' submergence the temperature of the water averaged 47° F., in the final test of nine weeks it averaged 55° F., and in four intermediate tests of from three to six weeks, 53° F.

In the light of the results of this series of tests the fact that a practical vineyard submersion requires at least two months' flooding is not a cause for wonder.

An observation made during the winter of 1913-14, from December to February, showed that hibernant larvæ can withstand short intermittent submersions in water interrupted by periods of low temperatures, even passing below 32° F.

On June 9, 1914, two experiments were conducted, bearing on the resistance of eggs of the radicle to heated water. In four of these tests the length of submersion was 90 seconds, and the temperatures ranged from 112.1° to 131° F.; in the other seven, the eggs were submerged 60 seconds under temperatures varying from 108.5° to 132° F. Results showed that a temperature of 123° F., with an exposure of 60 seconds, destroyed all eggs. For practical use it is desirable to have a temperature of at least 125° F.

In the experiments the eggs after treatment were placed on pieces of vine roots and observed for possible development. Temperatures of 123° F. or over killed the eggs immediately, but the lesser temperatures killed none or only a variable percentage. Those eggs not killed hatched normally.

During June and July, 1914, a series of tests was made with radicle eggs exposed to atmospheric temperatures varying from 76° to 90° F. for periods varying from 5 to 60 minutes. With a

shade temperature of 90° F., eggs exposed to sunlight were killed in 20 minutes. At a shade temperature of 76° F., 40 minutes' exposure to direct sunlight killed all aphids, but when placed in the shade the eggs resisted the maximum test of 60 minutes' exposure.

It is therefore apparent that eggs can resist the sun's rays to a considerable extent. The extent of their resistance to atmospheric temperatures in the shade can not be estimated, though it is of course greater than their resistance to direct sunlight. The eggs utilized in these tests were selected at random, and therefore were in various stages of embryonic development.

Experiments with the submersion in water of active newly hatched larvæ are detailed under the heading "Diffusion," which follows.

DIFFUSION OF PHYLLOXERA.

In European countries four natural means of diffusion are recognized: (1) By the winged insect; (2) by newly hatched wandering larvæ issuing from the soil; (3) by newly hatched wandering larvæ traveling through the soil; (4) by the gall-inhabiting form. To these there should be added casual means, as follows: Cultivating instruments, vine supports and picking boxes, plants between the vines, man and domestic animals, water, cuttings and rooted vines, phylloxerated land, and old stumps.

DIFFUSION BY FLIGHT.

Comparing the slower diffusion of the phylloxera in California with that of certain European vine-growing sections, it was from the first doubted that the winged form was a common diffusing agency, in spite of the fact that its production is often abundant in California vineyards on the roots of vines the second and third years after the initial infestation. This doubt became strengthened by (1) lack of leaf galls in nature and failure to discover winter eggs on a large number of vines of different varieties known to have been infested by migrants, or to have been close to vines thus infested; (2) the fact that, in confinement, during five years, thousands of migrants were utilized and only 72 sexual forms were secured, and, in turn, no normal winter eggs. On comparing the researches of European observers it is found, however, that in most cases they were unable to raise the sexual forms in confinement in any numbers, so this second point is inconclusive.

Grassi (11, p. 138-148) and his colleagues demonstrated that the insect which hatches from the winter egg always settles on the young vine leaf and becomes the gall-making stem mother (gallicole). They also found (11, p. 274-280) that there occurred a nymphlike form which deposited parthenogenetic eggs from which issued root-

feeding insects. This form generally occurred on resistant vines, but also on viniferæ along with the sexuparous migrants. The individuals exhibited much diversity in development, ranging from those with large wing pads to others bearing no vestige of wing pads, but having more fully developed eyes than the typical adult radicles. In nearly every case their eggs were parthenogenetic, the resultant larvæ becoming root feeders. This form has been styled "intermediate," in that it is intermediate in structure between the radicle and the winged form. Observations indicate that it occurs rather infrequently in California. It has been discussed under the heading "Nymphicals or intermediate forms" (p. 82). All the fully winged individuals observed in California which deposited eggs were sexuparous.

To sum up, it is not believed that in California there is diffusion through the winged form. It is perhaps worth while to record some observations upon the behavior of the insects of this form in the vineyard. During July and August, 1914, these occurred in a Zinfandel vineyard badly infested with phylloxera. Previously roots of many of the vines on lighter soil had been dug up, and it had been found that a large production of migrants was developing, especially on vines having the external appearance of not being badly phylloxerated. The condition of the roots on this type indicated that phylloxeration had not been in progress more than two years and the tuberosities had not reached a stage of advanced decay; but phylloxeræ were abundant, and it was evident that another year would find the vines much less thrifty. Sticky paper, tacked to boards, was placed in the vineyards, both on the surface of the ground in a horizontal position and in a vertical position. The horizontal papers were placed beside infested vines at distances varying from 6 inches to 5 feet from the trunks. The vertical boards were placed throughout the infested part and outside of the vineyard and extended from the soil surface to a height of $7\frac{1}{2}$ feet. More winged migrants were obtained on horizontal boards than on the vertical boards in proportion to a given area of paper. The majority of migrants caught on the horizontal boards were found at the edges, indicating that they reached the papers by walking rather than by flight. In some cases where individuals were found in the middle of the sticky papers it appeared that these might have fallen down from canes of the vine above, but in many instances the phylloxeræ obviously had reached the papers by flight or had been blown thither by the wind. Those on the vertical papers had either been borne by the wind or had flown voluntarily. On the vertical boards facing away from the prevailing wind no migrants were caught. Vertical boards with sticky paper were placed in the vineyard on the following dates: June 20; July 7, 10, 13, 21, 24, 31;

August 3, 7, 11, 14, 17, 20, 21, 31. Horizontal boards were placed July 10, 13, 21, 24, 31; August 7, 11, 14, 17, 21, 25, 31; September 5, 11, 26.

On the vertical boards eight migrants were captured between July 13 and August 21, and on the horizontal boards, between July 10 and August 17, 51 were taken. The area of paper exposed on the vertical boards was 63,725 square inches, almost 50 square yards, while that of the horizontal boards was 7,625 square inches, not quite 6 square yards. The papers kept sticky for about four days on the average. Considering the comparatively large number of migrants captured on the limited areas of sticky paper, there must have been a heavy infestation throughout the vineyard. Winged phylloxerae were observed on and about the bases of vine trunks, and many were caught in spider webs and died. Whether the migrants deposit the sexual eggs in the vineyard or not, the total absence of galls on the vines (viniferæ and resistentes) surely indicates that such eggs come to nought.

From rather meager observations it appears that the sexuals require a high temperature, coupled with considerable humidity, for their successful development, and that the climatic conditions of California lack the requisite combination.

DIFFUSION BY NEWLY HATCHED RADICICOLES ISSUING FROM THE SOIL.

In the summer of 1868, Faucon, in France, observed young radicoles wandering over the surface of the soil following a heavy rain, which had caused the soil to crack open in drying. He also observed the phylloxerae to enter cracks and disappear. In 1872, he again observed these phenomena between August 4 and September 30. The year following, his observations were made from June 14 to September 13, so that he was able to see wandering larvæ during a period of three months. In 1876, Boiteau, in France, confirmed the observations of Faucon, adding that he found that the greatest number of wanderers issued from vines at the periphery of the phylloxera "spot." Since then other observers have discussed the phenomenon of "wanderer" diffusion. Grassi (11, p. 351, 138, 148) and his colleagues, working from 1907 to 1911, conducted a series of experiments with the wandering larvæ. They found that these were strongly attracted to light and that in walking over the soil surface they did not go in a straight line, but deviated according to the variations of the surface. On a piece of glass they proceeded in a straight line and covered a distance of about 2 cm. the first minute.

As regards inoculation of vines by these wandering young, successful experiments were carried out in Europe on vines in pots, it being found that the wanderers penetrated the cracks formed between the inside periphery of the pot and the drying soil and infested

the rootlets growing in contact with the pot. Experiments showed that when sand was dry it obstructed the wanderings of the phylloxerae, but when moistened the phylloxerae might be drawn through it with the water. It was also found that in sandy soils water might occupy all the interstices between the grains of sand, repelling the phylloxerae, whereas in soils of other types air cavities existed sufficient to enable the phylloxerae to live.

In California the wandering larvæ were first observed in glass jars in which were kept phylloxerated roots in the summer of 1913. When such jars were removed from the darkness of the cellar to a light room, young larvæ were observed wandering up the sides of the jars. In the dark cellar such wandering took place, but after light was admitted to the jar the wandering became much accentuated. Similar wandering of larvæ was observed in the cages used for observations on living roots (Pls. V, VI, fig. 1; VII).

Until 1914 no vineyard observations in this direction had been made, but in that year wanderers were observed in their normal state. For these observations, vines in a phylloxera "spot" in a Zinfandel vineyard 10 years old were selected. This "spot" was situated on light clay loam upon sloping ground, and within its confines wandering larvæ were observed during July and August. These were found in greatest numbers coming from vines near the outer edge or periphery of the "spot." Such vines had little external evidence of phylloxeration, but upon examination it developed that the roots were heavily infested and produced many migrants as well as wanderers. From vines obviously moribund a smaller number of wanderers appeared. Wanderers also were obtained on the same horizontal boards with sticky papers on which migrants were caught. These were captured close to the edge of the sticky substance and never farther from it than 6 mm., and it appeared that all those taken had crawled to the papers and that none had been borne on the wind. On vertical papers, not even when placed within 2 feet of the wanderers, and to the leeward of them, were any phylloxerae captured. It was observed, however, that on favorable occasions wanderers are easily borne off by gusts of wind. The part of the vineyard in which wanderer activity occurred was moderately well cracked through drying. On the horizontal sticky papers wanderers were caught at points from a few inches from the vine trunk to 5 feet from the nearest vine and directly in the center of a square described with a vine at each angle. In this latter case either the phylloxerae had ascended by the trunk of the vines, and then walked 5 feet, or else they had ascended by means of cracks nearer the paper. In either case it is obvious that the spread of a given phylloxera "spot" may result from the activities of these wanderers without the agency of wind.

Wanderers were first caught on sticky papers July 21 and first observed alive in the vineyard August 11. After August 18, no more were caught on the sticky papers, and after August 25, no more were observed alive. The weather during July and August was for the most part bright and warm. In the vineyard the wanderers were observed in by far the greatest abundance near the trunks of the vines, and it appeared that they had reached the soil surface by following up the roots. No wanderers were observed on the aerial portions of the vines themselves. They showed much activity, wandering aimlessly around over the soil. They seemed to prefer the shaded parts, but appeared also on ground surface exposed to the sun. Large numbers were found dead close to the vine trunks, and these occurred in places where the soil was very fine, indicating that the phylloxeræ were unable to progress in fine soil. Laboratory experiments bore out this supposition. Many others became caught in spider webs stretched over the soil surface. The character of the soil in the vineyard in August, 1914, was such as to enable phylloxeræ to pass from one vine to another without necessarily encountering very fine soil, as no cultivation had been practiced since May, 1914, and the vineyard had been cultivated previously only in one direction.

As regards the capture of wandering larvæ upon sticky papers, the data given in Table XXXIV are of interest:

TABLE XXXIV.—*Wandering larvæ of the grape phylloxera; diffusion in vineyard; Walnut Creek, Calif., 1914.*

Date caught on paper.	Number of wandering larvæ caught.	Distance from nearest vine trunk.	Area of sticky paper on which phylloxeræ were caught.
		<i>Feet.</i>	<i>Square inches.</i>
July 21-24.....	3	5	135
July 24-28.....	1	2	135
July 31-Aug. 3.....	29	2	135
Do.....	1	5	135
Aug. 7-11.....	2	2	135
Aug. 11-15.....	1	$\frac{1}{2}$	135
Aug. 14-18.....	1	2	135

During the period from July 21 to August 18 many sheets of sticky paper 135 square inches in area (9 by 15) were placed on the surface of the ground, and wanderers were caught on 7 (see above) out of 32 papers. In the majority of instances the individuals were caught on the side of the paper toward the nearest vines, which would indicate that they arrived there straight from the trunk of the vine. On sides of the paper facing vines farther away it would be natural to expect fewer wanderers when one considers how the circumference of a circle increases in proportion to its radius, and also the comparatively equal diffusion of wanderers in all radii, if the vine

trunk is considered as the central point. On two occasions wanderers were caught on paper placed equidistant (5 feet) from four trunks of infested vines. Examinations showed that between one vine and another, even of apparently equal phylloxeration, a great variation in the production of wanderers took place. It also appeared that there was a tendency to produce these forms all at one time as though they had collected in a mass and then issued all together. As regards the time of day at which they were most abundant, it appeared that more might be observed between 10 a. m.¹¹ and 1 p. m. than at other daylight hours. European observers found that in general the wandering larvæ appeared in greatest abundance in the early afternoon, which is the hottest part of the day.

Vineyard observations were continued in 1915. The same vineyard was used, but more attention was paid to phylloxerated vines on the parts in which the soil was a heavy black clay. On this heavy soil no wanderers appeared before July 24, and none was found after July 29. The larvæ also were always very scarce, notwithstanding the fact that the soil contained numerous cracks which would enable the wanderers to reach the surface. On the lighter soil (clay loam), wandering larvæ first appeared July 14, and they continued to issue until August 18. During this period of over a month about two-thirds of the phylloxerated vines examined were producing wanderers. Between July 15 and 21 they were most abundant, as many as 20 or 30 living individuals being visible at one time beside the more heavily infested vines. In August hundreds of dead larvæ could be seen on the surface of the soil around the bases of the vine trunks, and large numbers were caught in spider webs. As in the previous year, the vines bearing the largest numbers of wanderers were those of recent phylloxeration.

In 1915, during the period of wanderer activities, the weather was for the most part quite hot and dry. Occasionally there were cool days, and on these the wanderers appeared to be as active as on the hot days.

It appeared certain that the great majority of the wandering larvæ ascended to the light by way of the main trunk of the vines, around which there occurred almost always a wide crack. More issued from Zinfandel vines than from Carignan vines equally phylloxerated, perhaps because the Zinfandel had thrown out more fleshy rootlets in May and June, and these had decayed in July while heavily infested. It would thus appear that many of the wandering larvæ are produced on these surface fleshy rootlets and leave them because they have become overcrowded or have started to decay.

In each of the years 1914 and 1915 wandering larvæ appeared in the vineyard over the same period, i. e., from the middle of July to

¹¹ All references to clock time refer to "Standard time."

the end of the third week in August. The condition of the soil was about the same in both years, moisture being somewhat higher than usual because of extra heavy precipitation each spring. The retention of moisture near the soil surface tends to produce many fleshy rootlets, and these in turn produce abundant nymphs and wandering larvæ. Thus a wet spring results in the early production of migrants and wandering larvæ.

A number of laboratory observations were made on the wandering larvæ. From these it appeared that the insects were capable of walking as much as 14 feet on a smooth surface, provided a strong light attraction was present. On fine soil their appendages became clogged very soon, and prevented further locomotion, but on hard surfaces, they progressed successfully. On warm surfaces they easily became "baked" to death, and in fact always lived the longest when least exposed to the sun, as the heating of the surface soil killed the aphids. Larvæ easily passed over wet sand and were able to make headway on dry sand, but could not penetrate sand. It was found that the larvæ could remain alive at least for three days, wandering around partly upon the soil and partly in cracks in the soil in a flowerpot subjected to an average amount of direct sunlight.

During the summer and autumn of 1914 a number of young rooted vines were planted in 9-inch pots, and these were inoculated during May and June by burying phylloxerated roots around the stalk or by transferring eggs to the larger roots. These vines included *vinifera*, American nonresistants, and resistants. On the top of these pots and resting on the earth were fitted tightly circular pieces of wood with a hole in the center, through which passed the stalk of the vine. The whole aerial portion of the vine was inclosed in a muslin cage. This construction was designed to compel phylloxera ascending to the soil surface to make their way through the hole around the stalk; and having done so, they would be unable to escape by reason of the white muslin cage and would soon die. In October and November these cages were examined, and in some of them small numbers of dead wanderers were found, in others none, and in still others very large numbers. Those containing dead wanderers in abundance were the ones in which the vines had been fertilized with chemical fertilizers, and there was also a corresponding abundance of winged migrants from such vines. The action of the fertilizers produced many migrants and many wanderers and invigorated the vines, yet in all cases a large root infestation by wingless forms persisted through the winter following. In the cages above mentioned fertilizers, in liquid form, were applied periodically during the summer. In 1915 a similar series of vines were fertilized with solid fertilizers at the time of planting in early spring, and

later observations showed that wanderers were no more abundant on fertilized than on check, unfertilized vines. On young vines in pots wanderers were often observed to ascend the vine stalks to 6 inches above the soil surface, and in one instance on an American nonresistant vine (Golden Champion) several of them fastened on the bark and matured there (1914). This vine was never exposed to the brightest light and, moreover, during 1914, within a radius of 4 inches from its stalk was placed a glass cylinder, around the bottom of which was fastened 2 inches of black paper, so that the stem of the vine received little light. In 1915 the glass cylinder and black paper were removed and no wanderers settled on the aerial portion, although from June 29 to September 10 a limited number of them could be seen almost daily ascending the stalk to about 6 inches as in the previous year.

During 1913 and 1914 many instances were observed of wanderers infesting the rootlets in the pots used in the cages for observations on living vines (Pls. V-VII). In these cases the wanderers were produced on the exposed portions of the roots, and wandering off these, they found themselves on the surface of the soil in the pots. They then proceeded to pass down through the cracks around the inside periphery of the pot, where the soil had dried, and finally reached the rootlets growing against the inside of the pot. Such infestations occurred on rootlets from the surface to the total depth of 9 inches. This infestation occurred during July, August, and September, and in November, when the vines were pulled up, most of the nodosities produced by the phylloxeræ had rotted. In some cases rootlets appeared above the soil around the periphery of the pot, and these were infested easily and abundantly through the agency of wandering larvæ. In the pots in which quartz had been substituted for earth for experiments with fertilizers, the wanderers were able to find their way down to the rootlets, although the cracks in the quartz were fewer and narrower than in the earth. It may be mentioned that the earth used in the pots in 1913 was a rather heavy dark loam, mixed with sandy loam, and in 1914 only the heavy dark loam was used. A layer of gravel and sand about one-fourth inch thick was laid on the surface, but this did not prevent cracking around the inside periphery of the pot. The heavier soil of 1914 seemed to allow of easier passage for the wanderers.

In the spring and summer of 1914 three vine section cages containing cuttings were placed together in a trench. Two of these were infested with phylloxeræ throughout May and June. On July 18 it was found that a vine in the third cage was infested with two egg-laying adults, each situated on a nodule. The vines in this section cage never had been inoculated, and it is certain that their in-

festation was caused by two wanderers from an adjoining cage. It was judged that this infestation must have occurred about June 20, when many eggs were hatching in the adjoining cages and many rootlets decaying, thus compelling the newly hatched larvæ to seek food elsewhere.

INOCULATIONS WITH WANDERERS.

On July 31, 1913, 30 wandering larvæ were taken from jars in the cellar and placed on pieces of sound severed roots in a petri dish. On August 13, 25 half-grown phylloxeræ found roaming around in jars were added. All the latter deserted the roots and died, but of the former, three matured August 25 to September 18. A later inoculation (Sept. 25) with 40 young wanderers resulted in none of these remaining. Another similar experiment was tried on September 29, with 40 young wanderers, but it also failed. Thus out of 135 individual wanderers only three matured.

In 1914 this experiment was repeated, and two pieces of sound severed roots were inoculated in a petri dish, one with 8, the other with 40 wanderers. In this case a layer of moist sand was placed below the roots, whereas in 1913, only filter paper had been used. Of the smaller lot 1 and of the larger lot 20 matured. Thus On August 28, 15 wanderers from jars in the cellar were placed on the living root of a Tokay, and 3 of these hibernated and developed the following spring.

In the autumn of 1913 an attempt was made to inoculate the roots of sound potted vines by means of wandering larvæ placed upon the surface of the soil in the pots. For this purpose, 35 wanderers were placed on the soil of each of four potted vines (Resistant hybrid, Sept. 18; Agawam, Sept. 23; Burger, Sept. 26; Thompson's Seedless, Oct. 6). In no case did the wanderers succeed in inoculating the roots. The soil, however, contained extremely few cracks.

The following year this phase was pursued further. Sound pieces of roots were planted 4 inches below the surface in four 9-inch pots. On July 8, 30 wanderers were placed on the soil surface of the first pot, the soil being cracked from having been watered the previous day. The root below was never infested. The soil of the second pot was watered to cause it to crack extensively. After it became well cracked about 25 wanderers were shaken on it, July 8. An examination of the root, August 25, showed it to be infested with a thriving colony of phylloxeræ. In the third pot the soil was not watered; consequently there was no cracking. On July 12, 50 wanderers were shaken out on the surface. No infestation of the root

below occurred. The soil of the fourth pot was watered sparingly, and few cracks were formed. July 17, 12 wanderers were shaken onto the soil. No infestation of the root below occurred. Only one out of the four experiments resulted positively, and in that one the soil was very well cracked, affording access to the root.

Inoculation of the wanderers on living vines was attempted through the following experiments: Five lots of four vinifera vines each were planted, two on light sandy loam and three on heavy clay loam. The vines were all young rooted vines, and they were planted roughly in the form of squares during the month of June. In the center in each one of four of the groups a phylloxerated vine (potted) was put in the ground at varying distances from the four surrounding vines. In one group the four outside vines were distanced, respectively, 14 inches, 2 feet, 3 feet, $3\frac{1}{2}$ feet from the central vine. In a second group they were distanced, respectively, 2, 3, 4, and 6 feet from the central vine. In the third group they were distanced, respectively, 2, 4, 6, and 8 feet from the central vine. In the fourth group they were distanced, respectively, 2, 3, 4, and 6 feet from the central vine. In the fifth group the four vines were potted, and in place of an infested central vine, infested roots were buried 1, 2, 3, and 4 feet, respectively, from the outside vines. In this last case the vines were potted to prevent possibility of underground inoculation. The four central vines remained infested throughout the summer, but it was not disclosed that they, or the buried roots, produced any wandering larvæ above the surface. The surface of the soil in the area used for these experiments was kept well cracked. In no instance did the 20 outside vines become infested.

In 1915, field experiments were conducted in a vineyard which had several large phylloxera "spots" both on light and heavy soils. The light soil might be described as a silt loam with a clay admixture, and the heavy soil was black, sticky clay. In spring a number of sound rooted vinifera vines 1 year old were procured and planted in 5-gallon kerosene cans from which one side had been cut. Different types of soil were used in these cans. The vines thus planted were kept apart until July, when they were carried out to the vineyard selected and planted level with the soil at varying distances from vineyard vines from which wandering larvæ were known to be issuing. To insure cracking of the soil, water was applied to the soil surface and also to the soil between the cans and the near-by vine. Wandering larvæ were observed in this vineyard from the middle of July to August 20. In September, after the wandering of the larvæ had ceased, the cans were dug up. Table XXXV gives the results of this experiment.

TABLE XXXV.—*Field experiments on inoculation of vines by wandering larvæ of the grape phylloxera, Walnut Creek, Calif., 1915.*

No. of vine.	Type of soil in can.	Variety of vine.	Date of planting can in vineyard.	Date of taking up can in vineyard.	Distance of vine in can from trunk of infested vine in vineyard.	Result.
					<i>Fect.</i>	
1	Silt loam.....	Mission.....	July 14	Sept. 8	2	Uninfested.
2	do.....		do.	Sept. 9	2	
3	do.....		do.	Sept. 17	1	
4	do.....	Zinfandel.....	July 15	Sept. 8	1½	Infested.
5	do.....		do.	do.	5	
6	do.....		July 17	Sept. 9	2	
7	do.....	Carignan.....	do.	Sept. 15	1½	Uninfested.
8	Heavy black loam, 2 parts; silt, 1 part		do.	Sept. 9	1	
9	do.....		July 20	Sept. 15	4	
10	do.....	Zinfandel.....	do.	do.	1½	Infested.
11	Heavy black clay loam.....		July 21	Sept. 9	1½	
12	do.....		do.	Sept. 17	1½	
13	do.....	Zinfandel.....	do.	Sept. 15	5	Uninfested.
14	Sandy silt.....		July 22	do.	4	
15	do.....		do.	Sept. 17	2½	
16	do.....	Carignan.....	do.	Sept. 15	2½	Uninfested.
17	Pure sand.....		do.	do.	2½	
18	Heavy black clay loam.....		July 24	do.	1	
19	Sandy silt.....	Zinfandel.....	do.	do.	1	Uninfested.
20	Heavy black loam, 2 parts; silt, 1 part		do.	do.	1½	
21	Heavy black loam, 1 part; silt, 1 part.		do.	Sept. 8	8	
22	Heavy black clay loam.....	Carignan.....	do.	do.	4	Uninfested.
23	Sandy silt.....		do.	Sept. 15	1	
24	Heavy black loam, 2 parts; silt, 1 part		do.	do.	3	
25	do.....	Zinfandel.....	July 27	Sept. 17	¾	Uninfested.
26	Heavy black loam, 1 part; silt, 1 part.		do.	do.	4	
27	do.....		do.	do.	2	
28	Pure sand.....	Zinfandel.....	do.	do.	1½	Uninfested.
29	Sandy loam.....		do.	do.	1½	
30	do.....		do.	do.	5	
31	Heavy black loam, 1 part; silt, 1 part.	Zinfandel.....	July 29	do.	2	Uninfested.
32	Heavy black clay loam.....		do.	do.	2	
33	Sandy silt.....		do.	do.	2	

¹ Entire vines died shortly after having been planted in vineyard, therefore can not be included in results of experiment.

Of the 27 vines which were alive when the cans were taken up, 21 had been planted in the phylloxera "spot" on light soil and 6 in phylloxera "spots" on heavy black clay. None of the latter and only 4 of the former group became infested. Vine 6 was examined September 9, and an infestation consisting of 1 adult radicle and about 12 larvæ was found. This indicated that a single wanderer had established itself on the vine. On vine 11, on the same date, there were found 3 adults and about 20 larvæ. On vine 12 on September 17 there were 6 adults and about 200 larvæ, besides many eggs. On vine 13 on September 15 there were over 350 phylloxeræ, including some 50 adults. Vines 11, 12, and 13 were planted around the same infested vine. In the case of vine 13 the infestation was started either by a large number of wandering larvæ in August or more likely by one or two wanderers directly after the vine was planted on July 21. Since in August the phylloxera generation cycle may be passed in less than 22 days, and since each mature radicle may average 8 eggs per diem for several weeks, it would have been possible for the infestation on vine 13 to have developed

from a single wanderer. Similarly, it is possible that the infestations on vines 11 and 12 originated with one individual each.

In all of four inoculated vines the infestations were confined to the larger roots, and there was no nodositous infestation such as occurred with wanderer inoculations in potted vines at the laboratory. This is explained by the fact that the soil in the cans did not crack deeply enough to reach the rootlets (none of which came near the soil surface) while it cracked badly around the base of the stems of the vines. It is therefore most probable that the wandering larvæ passed down the vine stem. Cracks of 1 foot or more in depth were quite abundant in the vineyards in July and August, and it was possible to find rootlets such as form nodosities when punctured by phylloxeræ at a depth of 6 inches from the soil surface. At that time of year there is generally in the vineyards a wide crack about the base of the vines, and it is through these cracks that the great majority of the wandering larvæ ascend to the surface. In the vineyard a wanderer could never be kept under observation long enough to be sure that it entered a crack permanently, therefore, with the purpose of seeking a root. Wanderers readily enter any crack which they can not bridge but frequently reappear after a short period of time. In pots they have been observed to enter whatever cracks they encountered, subsequently inoculating roots buried below. In other experiments with pots the wandering larvæ have been found to crawl down the crack between the soil and the inner side of the pot and inoculate the rootlets growing around the inside of the pots. Also it has been observed that in the vineyard experiments the inoculation was probably made by the wanderers crawling down the stem, since no other available cracks were favorable. In the vineyard, therefore, it is assumed that the wanderers enter the first crack they encounter.

In the experiments of 1914 with sticky papers, wandering larvæ were captured at varying distances up to 5 feet from the nearest infested vine. The four inoculated vines the year following were 2, $1\frac{1}{2}$, $1\frac{1}{2}$, and 5 feet, respectively, from the nearest infested vines. It should be said that there was a possibility that the infestations were inoculated by wanderers coming from infested vines at a greater distance. In the instance of the three inoculated vines planted in cans around one single vineyard vine it is reasonably certain that all three became inoculated from the central vine. From this vine large numbers of wanderers were observed to issue.

No vines were planted more than $5\frac{1}{2}$ feet away from a vineyard vine, the vineyard being planted 8 by 8 feet.

The soils used in the cans were of different types, but no satisfactory conclusions were drawn from this feature. It was noted that the

vines planted in lighter soils grew poorly and that the percentage that died was greater than in the case of heavy soils.

In 1914, wanderers were taken from jars in the laboratory cellar and successfully colonized on pieces of roots. It was found that they developed into the usual type of radicle phyloxera. In order to ascertain definitely the future of wanderers observed in the vineyard a thrifty section of sound grape root was transported to the vineyard on July 17, 1915, and 12 larvæ, wandering upon the surface of the soil, were placed thereon. Four of these subsequently matured as wingless radicles between August 23 and 27, and before the advent of winter a considerable colony was established. A contemporary experiment of similar nature was carried out with a like result with larvæ taken wandering on the surface of the soil in pots containing infested vines.

In conjunction with the inoculation experiment in the vineyard four Zinfandel vines were planted in kerosene cans in the laboratory yard, and after watering to insure soil cracking they were inoculated artificially by placing the larvæ on the soil surface. These inoculations comprised, respectively, 21, 190, 300, and 625 wanderers collected during the summer. Two of the cans contained sandy silt and two heavy black clay. In no case did infestation result.

For another experiment two galvanized-iron cans, 4 by 4 inches, and 10 inches deep, were used. Sound pieces of vine root were placed in each, 7 inches below the soil surface, and the cans then filled to the top, one with sandy silt and the other with heavy black loam, after which the cans were buried, their tops at a level with the soil surface. The surfaces were watered to insure cracking of the soil. Between July 15 and August 4, several hundred wanderers were placed on the sandy silt, and between July 18 and August 4 several hundred on the black loam. On August 27 the roots in the cans were examined. Those buried in the sandy silt which had failed to crack much were uninfested, while those buried in the heavier soil bore a small infestation, indicating that one or more wanderers had penetrated to the roots.

From the results of experiments on natural and artificial inoculations of vine roots by wandering larvæ through the soil two facts stand out: (1) Notwithstanding the large numbers of wanderers available or utilized, positive results were infrequent. In the years 1913, 1914, and 1915, altogether 14 vessels containing vine roots, either living or cut into sections, were inoculated by placing wanderers on the soil surface, and only two of these gave positive results. The average number of wanderers used for each vessel was about 150. In the vineyard experiment in 1915, only 4 of 27 exposed vines became inoculated, yet all these vines were planted near vineyard vines

from which wanderers were issuing. It is true that the soil surface inside the cans was a small area—126 square inches—and that the soil itself was not as thoroughly cracked as it might have been; but in many instances the cans were not more than 1 foot from the trunks of the infested vines, therefore, from the wanderers when they issued, whereas in vineyards vines are set 6 or more feet apart.

(2) The presence of cracks in the soil leading directly to roots is necessary to permit the wandering larvæ to descend to roots, for the larvæ can not dig their way through the soil, and during the period when they are issuing, rain, which might provide moisture to draw them into the soil or wash them onto exposed roots, is lacking.

The writers are of the opinion that wandering larvæ are the cause of considerable local spread of phylloxera, that is, within the vineyard or district; and that they are instrumental in causing the formation of new phylloxera "spots" or foci. Under favorable conditions it has been proved that they may live for at least three days above the surface of the soil, and thus may be transported from place to place with the possibility of finally becoming located on a vine root. There is no reason why wanderers may not live for as long as two weeks on the soil surface without feeding, provided this surface is not heated by the sun. In one instance, after being placed on a piece of root, several of them wandered for as many as five days before settling down to feed. It may be said also that larvæ have been found to live in water as long as nine days without food, and it may thus be assumed that they might remain as long in the open air under average conditions of temperature and humidity. This fact would explain how the insect may be spread from one locality to another by wandering larvæ that lodge in such vine material as picking boxes (see following under "Casual agencies of diffusion," p. 115).

There are certain marked instances in California vineyard districts where phylloxeration has developed "with the prevailing winds." The only wind-borne forms of the phylloxera in California are the winged migrants and the wandering larvæ. The California biology indicates that the migrant has no bearing on the preservation of the species, and therefore such phylloxeration has resulted from wind-borne wandering larvæ.

DIFFUSION BY NEWLY HATCHED RADICICOLES TRAVELING THROUGH THE SOIL.

In 1914, experiments on subterranean diffusion were conducted. In April three Muscat rooted vines were planted in a 4-foot square box containing heavy loam covered with a 3-inch layer of fine sand. The sand was used for the purpose of preventing wandering larvæ from emerging upon the surface and reaching the sound vines. May 20,

one of the vines was artificially inoculated. The second vine was 1 foot distant, and the third 2 feet distant from the first. On October 10, all three vines were dug up, and it was found that the first had a small infestation all over the root system. The second vine had a small infestation chiefly on nodosities on roots nearest those of the first vine. So far as could be observed, the roots of the two vines did not approach nearer than 2 inches at the closest point, but as some of the terminal rootlets had died during the summer and autumn it is quite possible that earlier in the season rootlets of the two vines were contiguous. The third vine was uninfested. Its roots had been separated from those of the first vine by at least 12 inches and from those of the second vine by at least 5 inches.

This experiment did not appear to show that subterranean infestation was a common mode of diffusion. The condition of the roots on the first vine when it was pulled up showed that its summer infestation had been large and that many wanderers had been produced; therefore, one would expect that some of these would have found their way to both of the other two vines. The earth at the time of planting, however, had been packed very solidly, and the layer of sand prevented cracking so that there were very few, if any, subterranean passages affording access to the phylloxeræ.

The following experiments also were made: On May 22 two young *vinifera* (Feher Szagos) were planted in a galvanized tin, 8 by 8 by 10 inches. Two sides of this tin were basally produced in the shape of a cone (Pl. VI, fig. 2, p. 52), and at each apex was a hole of one-half inch diameter. The cones were then tightly fitted into wooden tubes, through the centers of which ran a square passageway of one-half inch diameter, and the junctions cemented. The cones and wooden tubes were buried 8 inches below the soil surface. At the farther ends of the two wooden tubes similar galvanized tins were connected, and in each of them was planted a single sound vine (Feher Szagos). In this experiment the tubes were, respectively, 2 and 10 feet in length. The conical projections were expected to draw the roots toward the hole, therefore toward the tubes. No earth, except for about 2 inches at the ends, was placed in the passage in the tubes. Black paper was glued on to the top of the outside of the wooden tubes so as to prevent entrance of light. Thus the phylloxeræ, if they passed through the hollow inside of the tube, would not be influenced by any light rays. On September 23 the tins and tube were pulled up and the vines examined. Both central vines inoculated in May were well infested. Their rootlets and those of the two end vines had penetrated not more than 3 inches into the hollow of the tube, but in all four cases rootlets were abundant inside the conical projections. The vine at the end of the 2-foot tube was well infested with

radicicoles in all stages and with a few nymphs, indicating that the original infestation occurred at least before August 1. The vine at the end of the 10-foot tube was uninfested and showed no indications of ever having been inoculated.

On May 22 a similar experiment, with single vines (Carignan), was started, the length of the wooden tubes being 6 and 14 feet, respectively. On September 30 the vines were examined and the roots of the central vines were found to be well infested. Rootlets of all four vines had penetrated not over 3 inches into the hollow interior of the tubes. The vine 6 feet distant from the infested vines showed a good infestation, whereas the vine 14 feet away was not infested.

Thus, wandering larvæ, in two cases out of four, had found their way along the whole length of the interior of the tubes and had inoculated the roots at the farther ends of such tubes. The inoculated vines were those at the ends of the two shorter tubes (2 and 6 feet), and the sound vines those at the ends of the two longer tubes (10 and 14 feet). Thus it would appear that there is a limit to the distance over which the phylloxeræ will proceed when they have left a root, intent on finding new food. These experiments with wooden tubes demonstrated the wandering habits of the young radicicoles, and it may be readily understood how this subterranean movement may cause a phylloxera "spot" to enlarge, especially when the soil is cracked to any depth.

DIFFUSION BY YOUNG GALLICOLES.

In districts where the gall-inhabiting forms (gallicoles) are found, they may be the cause of diffusion. Either the branches of vines intertwine and the young gallicoles pass thus from one vine to another, or the young gallicoles are carried by the wind on to foliage of other vines or to the ground. Since the gall-inhabiting form is normally absent in California, this means of diffusion will not be discussed further.

CASUAL AGENCIES OF DIFFUSION.

CULTIVATING INSTRUMENTS.

During May and June badly phylloxerated vines are accustomed to put forth an abundance of short fleshy or fibrous rootlets close to the surface of the soil. Usually these are infested heavily with the progeny of the overwintered phylloxeræ. The vineyards usually are cultivated and hoed at this time, and these surface rootlets are frequently broken off and carried along by the cultivator and hoe. This possible means for spreading the insect having been considered, a series of experiments was initiated as follows: On May 30, in the vineyard, pieces of infested fleshy surface rootlets were secured, placed in earth, and the whole transported to the laboratory. Four

lumps of earth and roots were partially buried in the soil of a pot containing a young sound vine (Pierce Isabella). The earth and roots exposed to the sun quickly dried up and no infestation to the vine resulted. It may be stated that the diameters of the lumps varied from one-half to 2 inches. On June 4 the experiment was repeated, but the infested fibrous rootlets were wrapped loosely in four lumps of earth with diameters $1\frac{1}{2}$ to 2 inches, and half buried in the soil of a pot having a sound vine (Cornichon) growing in it. The rootlets kept in good condition and the phylloxeræ lived four days (one of which was cloudy and rainy). On September 3 it was found that the vine showed a rather scanty infestation. On July 16 many strongly infested fleshy rootlets found in the vineyard, from 4 to 8 inches below the soil surface, were inclosed in a large piece of earth, half buried in the soil of a pot in which grew a sound vine (Carignan). On September 3 the vine was found to be strongly infested, especially on its upper rootlets near the inner periphery of the pot. On July 17 the experiment of the day previous was repeated in its entirety, with a Pierce Isabella vine, and on September 3 this vine was found to be severely infested, bearing many nodosities both on the upper and lower rootlets. Thus in three out of four attempts success was obtained in securing an infestation upon sound vines by placing pieces of infested rootlets in lumps of soil half buried in the earth of the pots in which those vines were growing. In practice it would very frequently happen that such rootlets severed by a cultural instrument would be buried several inches deep after being dragged along by the instrument. It is easy to understand how the insect might be diffused in this manner.

VINE SUPPORTS AND PICKING BOXES.

Vine supports or stakes (universally used), by reason of the fact that they enter the soil contiguous to the main stem of the vine, are very likely to bear phylloxeræ upon them. Since the newly hatched larvæ can live for at least three days, and probably many more, out of the soil and when not exposed to the sun's rays, it is apparent that infested stakes could be transferred to a considerable distance and when set out in a vineyard upon their arrival could be the origin of phylloxera infestation.

Many growers have declared that in their vineyards the phylloxeræ first showed evidence of their presence at a point or points where picking boxes coming from infested vineyards had been piled. If picking boxes were scattered in an infested vineyard during the time of the aerial wanderer migration, one can readily see that the opportunity would be afforded for the phylloxeræ to climb upon them, later to be transported to other vineyards, since it is a common

practice to use the same boxes many times in the picking season, and the same boxes may be used in more than one vineyard or district. In California, wine grapes are rarely picked before the middle of September, and raisin grapes are picked toward the end of August. In the experimental wine-grape vineyard, wandering larvæ were not found issuing after August 25, but in young vines in pots they were collected well into September. The fact that the wanderers were not found issuing in the wine grape vineyard at the time when picking boxes were distributed to a certain extent invalidates the theory of spread by these boxes. It is within the realm of possibility, however, that the latest issuing wanderers remained active and alive until the boxes were distributed some two weeks later. Observations on wanderers issuing from potted vines lead to the conclusion that the natural period of wanderer issuance may be considerably lengthened beyond that which was found to obtain in the experimental vineyard during the years 1914 and 1915. This longer period would include the time of picking wine as well as raisin grapes.

PLANTS BETWEEN THE VINES.

Walnut trees planted in vineyards indicate the possibility of diffusion through the agency of plants. The long roots of the walnut offer facilities for phylloxeræ to spread whenever vine roots come in contact with them or are very close to them. That phylloxeræ have been found moving on these roots would indicate that the latter often provide an underground channel of diffusion.

MAN AND DOMESTIC ANIMALS.

The possibility of the portage of phylloxeræ by man and domestic animals should not be overlooked. The winged forms and aerial wanderers may be blown on clothes or animals, and thereby spread, or they may be picked up with wet earth. This latter chance is greatly lessened under California conditions, because during the months in which wanderers and winged migrants are produced, the surface soil is dry, and the winged migrant is not a factor in diffusion.

WATER.

Recognizing the possibility of the spread of phylloxeræ through the agency of flowing water, the writers conducted the following experiments in 1914: From May 5, 11 a. m., to May 6, 11 a. m., a piece of severed root, infested by six adult overwintered phylloxeræ and about 100 eggs and larvæ, was subjected to a stream of water for the most part playing directly upon the insects and flowing 6 feet to an uninfested vine (Catawba) so as to effect contact with some of its roots and

also to stand on the surface of the soil about its stem. Examination of the piece of severed root after the experiment was concluded showed that about 40 eggs and young had been washed off. Five of the adults suffered no injury from exposure nor did most of the remaining young and eggs. On July 12 the Catawba vine was found to bear a strong nodositous infestation. On June 6, for eight hours, two pieces of severed roots bearing a total of about 200 phylloxeræ were subjected to a similar stream of water which subsequently flowed 6 feet to a sound Mission vine. On the severed roots the majority of aphids were not washed off. In this instance the roots of the living vine were not bared, and there were no cracks on the surface of the soil around it. On July 27 this vine was examined and found to be uninfested. The third experiment took place July 29. For eight hours two pieces of severed roots bearing a total of about 250 phylloxeræ were subjected to a stream of water which subsequently flowed 10 feet to a sound Feher Szagos vine growing in a pot. The surface soil in this pot had been previously watered, and thus was cracked. After the experiment was concluded, it was found that very few of the phylloxeræ had been carried off the severed roots. September 16 the vine was examined, but it proved to be quite uninfested. In each of these three experiments a fine stream of water was used and the angle of declivity was slight. In the first experiment only, wherein the roots of the living vine were actually exposed to the stream of water, did an inoculation through water agency occur. It is evident, however, that diffusion may occur by means of water-borne phylloxeræ. In the California vineyards such a condition could arise normally only between November and May, for in the other months it is very rare to have rain in any abundance. In April and May, however, when the phylloxeræ are active, heavy rains occasionally occur, and sometimes on the hillside vineyards deep waterways are formed, exposing the roots of vines to a depth of more than a foot.

In this connection some laboratory experiments were made upon the resistance of eggs and larvæ to water exposure. For this purpose small-sized glass vials and distilled water at about 64° F. were used. In one instance, in a corked vial, 9 out of 12 eggs hatched from 2 to 10 days after they were placed in the water. All those that hatched remained on the surface, while those that failed to hatch went to the bottom of the vial. In another instance eight recently deposited eggs were placed on the surface of the water in an uncorked vial. Six days later all had sunk to the bottom, but subsequently hatched. In a third experiment 11 well-advanced eggs were placed on the surface of the water in an uncorked vial. After 11 days all the eggs had hatched, six having remained on the surface and five having sunk to the bottom. In all three experiments the hatched larvæ failed to fasten to pieces of roots provided for them.

In a fourth experiment 26 eggs were placed in water in a stender dish. Two days later all but four eggs had sunk, but subsequently all eggs hatched and none of the resultant larvæ settled on the roots provided for them.

Table XXXVI indicates the results of experiments bearing on the behavior of newly hatched larvæ in water.

TABLE XXXVI.—*Behavior in water of newly hatched larvæ of the grape phylloxera, Walnut Creek, Calif.*

Date placed in water.	Number of individuals that—		Length of submersion.	Number of individuals after submersion.		Remarks.
	Sank.	Remained on surface.		Alive.	Dead.	
			<i>Days.</i>			
May 12	5	3	1	8	0	In stender dish without cover.
12	4	2	2	6	0	In small vial—uncorked.
27	2	0	2	2	0	Do.
15	4	2	3	2	4	In small vial—uncorked; sunk aphids dead.
19	5	1	3	1	5	Do.
June 1	4	2	4	1	5	In small vial—uncorked; sunk aphids alive.
May 24	1	1	5	1	1	Do.
June 1	0	4	6	3	1	In small vial—uncorked.
16	5	1	7	5	1	In small vial—uncorked; sunk aphids alive, but none subsequently fastened on root.
						In small vial—corked.
16	5	2	7	0	7	Do.
1	0	4	9	1	3	
July 15	6	2	4	8	0	In small vial—corked; one aphid subsequently matured Aug. 12 on severed root.
15	6	2	4	8	0	In small vial—uncorked; one aphid subsequently matured Aug. 11 on severed root.

NOTE.—In all except the first experiment, distilled water was used; in the first experiment, tap water.

Prior to June 16 the phylloxeræ were not followed up after their submersion to see whether they would fasten to the pieces of roots provided for them because the experiments were made only to ascertain how many of the larvæ would be alive after submersion. It may be noted that in some cases the larvæ which sank were found to be alive when removed from the water and in others those that floated were living when removed. The phylloxeræ survived as many as nine days on the surface of the water, and as many as seven days when submerged, and at the bottom of the vial. The experiments, however, did not continue beyond nine days, and there is no reason to believe that the insects could not live in the water many days longer than that period. The fact that they did survive as long as a week was sufficient evidence of the importance of their resistance to water. The two experiments of July 15–19 demonstrated that after four days in water the young larvæ could settle on pieces of roots and later mature. In the seven-day experiment, none settled on the roots. In all except one of the vials distilled water at about 64° F. was used. The behavior of the young phylloxeræ in water was characteristic. Those on the surface were active,

swimming around in circles, but those at the bottom remained almost motionless unless disturbed.

To sum up, it appears: (1) That eggs of radicolæ hatch readily in water, floating and sunken; (2) that the newly hatched larvæ may live for more than a week submerged, or on the surface film; (3) that these larvæ are capable, at least after four days of exposure to water, of fixing upon roots and developing in a normal manner. Further proof of the ability of young phylloxeræ to live submerged occurred in an observation made from September to November, 1914. A *Riparia* cutting had been placed in a glass vial in the laboratory. Immediately a callus formed, and many rootlets grew around the inside of the vial. On September 15, 20 eggs of radicolæ were floated on the water surface. None of the resultant larvæ persisting, more eggs were floated October 10. October 12 the water had evaporated, and four days later two young larvæ had settled. These had hatched after the water evaporated. About 1 inch of water was then poured into the vial to cover completely all the rootlets and the two phylloxeræ. October 22, three larvæ were observed under water, one of which had been fixed since October 16. October 27, there were visible under water, besides the original larvæ of the 16th, six additional larvæ, five of which were settled. October 30 all seven observed on October 27 had settled and an eighth was visible moving over the rootlets. A small tuberosity had been set up by one of the phylloxeræ. All the unhatched eggs had died. It was noted that when the insects were exposed to sunlight they moved their appendages actively. November 2, three settled larvæ were visible. These included the individual on the tuberosity and the one which had settled October 16. All others were dead. November 10 the only survivors were the original settler and the individual on the tuberosity. Shortly after November 20 all disappeared. Thus one individual, destined apparently to hibernate, persisted more than a month fixed on a root under water, and several others lived under water from 3 to 14 days.

There also exists the possibility of infestation by seepage. On vineyards of porous soils young larvæ on the surface may be drawn into the soil in time of a storm or irrigation. Also on steep hillside vineyards in the springtime, when heavy rains may fall or when a rise and fall in the "water table" may occur, a seepage infestation may take place. Any artificial irrigation during the months June to October invites the spread of phylloxeræ because in this period phylloxeræ occur above the surface of the soil or are active on surface rootlets.

CUTTINGS AND ROOTED VINES.

In European countries where a small percentage of the winter eggs are deposited under the bark of yearling wood there is a slight

danger of phylloxera infestation following the planting of a cutting from such wood. This danger does not exist in California, provided the cuttings are not "heeled in" before transportation, because the winter egg does not persist successfully. If the cuttings are "heeled in" before transportation in an infested district, the possibility of their becoming phylloxerated exists. Similarly, the possible danger from gallicoles remaining upon the foliage of canes late into autumn is nullified, because the gall-inhabiting forms do not normally occur in California.

The greatest danger of phylloxeration resides in the planting out of infested rooted vines. This is a very abundant means of distributing phylloxera. Even if only one or two out of a thousand vines are infested at planting, a "spot" or "spots" will form within a few years, and the whole acreage eventually will become infested. While the vines remain small, diffusion is slow because the roots of one vine are separated from those of its neighbors, and underground diffusion thus is rare if not impossible. Also, the relatively small number of roots, coupled with the relatively small number of phylloxeræ able to flourish thereon, prevents many opportunities for aerial diffusion by wanderers. If the majority of the vines planted out contain phylloxeræ, however, the vineyard's complete phylloxeration is not long removed. In a phylloxerated district the employment of resistant roots obviates the necessity of treating the vines before planting out in the vineyard, yet danger exists in cases where grafted vines are planted too deeply and the stouter vinifera scion is enabled to send out its own roots, in many instances crowding out the roots of the resistant stock. The scion's roots, being nonresistant, decay when phylloxerated just as though no resistant stock had been employed, and the expense and trouble of the grafting process are wasted. Even though phylloxeræ live on resistant stock roots in grafted vineyards without necessarily injuring the crop or vines, there still remains the possibility that infestation will arise from these grafted vines and that nongrafted vineyards near by will become inoculated. Such a possibility is accentuated the greater the proximity of two such vine areas, and especially if the nonresistant area is to leeward of the grafted area or if water flows from the grafted to the nonresistant vineyard. It is advisable, therefore, to disinfect even resistant roots when these are to be planted in a region free from phylloxera.

PHYLLOXERATED LAND.

Experiments with potted vines have given proof that phylloxeræ may live at least 10 months on buried severed pieces of roots, and also that such pieces may remain sound for 18 months and at the termination afford acceptable food for the insect. It is evident, there-

fore, that the planting of vines on land from which phylloxerated vines have recently been pulled up is a dangerous procedure. It is next to impossible to pull up grapevines without leaving pieces of roots in the ground. In the case of vine nurseries, this danger is very apparent.

OLD STUMPS.

Since the phylloxeræ may live under the bark of vine stumps to several inches above the soil surface, it is apparent that these infested stumps might possibly be a means of diffusion if sound vines should be placed near them. Such stumps, however, soon decay after they have been pulled from the ground and severed from their roots. In the active season, however, any insects dwelling upon them would hasten to leave and seek other food, so that in this season it is quite possible for diffusion to occur from the stumps. In the winter the phylloxeræ would all be hibernants, and these would die as the stump decayed.

SUMMARY.

HISTORY.

The grape phylloxera was introduced into California about the year 1858, having been brought on vines imported by settlers from the East. It thus appears that the pest arrived on the Pacific coast at least as early as it reached France, where the first evidence of its activity was vaguely noted in 1862.

For many years previous to this introduction the Spanish settlers and Missions had cultivated on a moderate scale the Mission grape, and this, though a very susceptible variety, as was afterwards proved, had flourished without disease. About the time of the advent of the phylloxera grape culture was receiving a great impetus, and many European varieties were being introduced which shortly showed signs of disease in localities in which the eastern vines had been planted.

The phylloxera has since spread throughout most of the grape districts of California wherever conditions have been suited to it, but never has the pest assumed such disastrous proportions as it did during the first years of its ravages in France. It is possible that the insect has never reached such isolated vine districts as those of the southern California counties, but in many of such isolated localities the conditions are unsuited to the insect, and thus we can not be certain that it did not reach these places and fail to establish itself.

Coming upon the scene at the infancy of the commercial grape industry, the phylloxera has been present throughout the growth

of that industry and, it is estimated, has in the course of some 60 years destroyed about 75,000 acres of grapes.

In many instances the insect has been distributed through the agency of infested rooted vines imported into an uninfested district or vineyard. In other cases the insect has been carried on vineyard material. In no instance has the distribution been as rapid as that which took place in the vineyard districts of France. The modified life cycle in California, i. e., sterility of the winged form, coupled with topographic barriers, consisting of mountain chains and dividing valleys, is in very great part responsible for this.

VINEYARD DESTRUCTION.

There is great variation in the rapidity of the destruction of vines and vineyards by phylloxera.

Apart from some variation in the different grape varieties, soil conditions must be considered as of great importance. In poorly drained soils the vines succumb much more rapidly than in well-drained land. Accumulation of moisture in the subsoil materially assists in the decomposition of infested roots, whereas if the subsoil is well drained, vines may flourish notwithstanding infestations extending over many years. Vines attacked when young and before their root systems have become established will succumb more rapidly than will those infested at a greater age.

The first indication of phylloxera in a vineyard occurs in the form of one or more stunted vines and a premature yellowing of the foliage. In time, adjacent vines will show similar indications, and those first infested are more noticeably stunted. Gradually more and more of the surrounding vines are affected, and those in the center become very much weakened or die outright. Thus are formed the so-called "oil spots" or foci for the distribution of the disease, which may be likened to the ever-increasing concentric circles of waves that are formed when a stone is cast into placid water.

Following the initial infestation of a vine under favorable conditions for phylloxera, the insects multiply rapidly, and within two or three years increase their range to involve the entire root system. Those which settle on the growing rootlets form fleshy lesions or swellings, which are termed nodosities. These swellings are generally somewhat curved, the insect inhabiting a depression of the inner arc. In the great majority of instances the insect stops further apical growth of the rootlet, and thus the rootlet ceases to supply nourishment to the vine. Although the percentage of rootlets thus infested is often large, a vine of vigor can easily send out more and continue to draw its nourishment from the soil. Other phylloxerae settle on the older roots and in most cases cause swellings termed tuberosities,

which vary in size, but the majority are about one-fifth of an inch in diameter. They are frequently very abundant, and two or more may coalesce. The bark of the root often cracks longitudinally, and a chain of swellings arises from phylloxera punctures. As long as these swellings remain fresh, the health of the vine is not much impaired, but as soon as they decay the vine is injured, and when they decay in numbers the roots are frequently destroyed, causing first the stunting and subsequently the death of the vine.

BIOLOGY.

The grape phylloxera was named in 1855 by Fitch in America from the gall-inhabiting form, and in 1868 by Planchon in Europe from the root-inhabiting type. In 1870 Riley and Lichtenstein proved that the two forms were two separate phases of a single species; consequently, Fitch's specific name *vitifoliae* must be conceded priority.

In its native region, eastern North America, the insect has a very complicated life cycle, which includes an aerial gall-inhabiting form. In California the gall form has been observed only once and that in the year 1884.

The California life cycle (fig. 10), as indicated by research, is much more simple than that which obtains in the East, and as far as the economy of the insect is concerned, is purely parthenogenetic.

Winter is passed in the form of the hibernant larva. Virtually all hibernants are newly hatched larvæ which settle down to hibernate immediately after hatching from the egg in the autumn, but a few hibernate in an older stage. Coincident with the first flow of sap in spring, these hibernants commence to feed, and mature on the average five and a half weeks later. The hibernant larva is light brown in color, and is about one-third millimeter long and half as wide. The mature hibernant is about 0.75 mm. long and 0.40 mm. wide, and does not differ from the adult radicle of any other generation. On the average, it takes the hibernant six months to mature, the period ranging from four and a half to seven and a half months. The mature hibernant gives rise to a number of generations—as many as eight—of root-feeding phylloxerae throughout the summer and autumn. Although somewhat arbitrary, April 15 to October 15 best indicates the period of the active half-year of the insect, the period October 15 to April 15 being the dormant or hibernating season.

All forms of the phylloxera are oviparous. The average number of eggs per adult radicle is about 110 and the average egg-laying period about 45 days. Incubation varies with temperature and lasts from 5 days in midsummer to over 30 days in December. The eggs

are lemon yellow and oval. Upon hatching from the egg, the bright-yellow larva seeks food. Larvæ hatching in spring mostly settle near the eggshells, but in summer and autumn a considerable percentage travel along the roots or forsake the vine altogether, either following cracks in the soil to reach neighboring vines or ascending to the surface of the soil and traversing the ground in their endeavors to reach other vines. To those that voluntarily forsake the vine has been given the term "wanderers." The larvæ molt four times, and on the

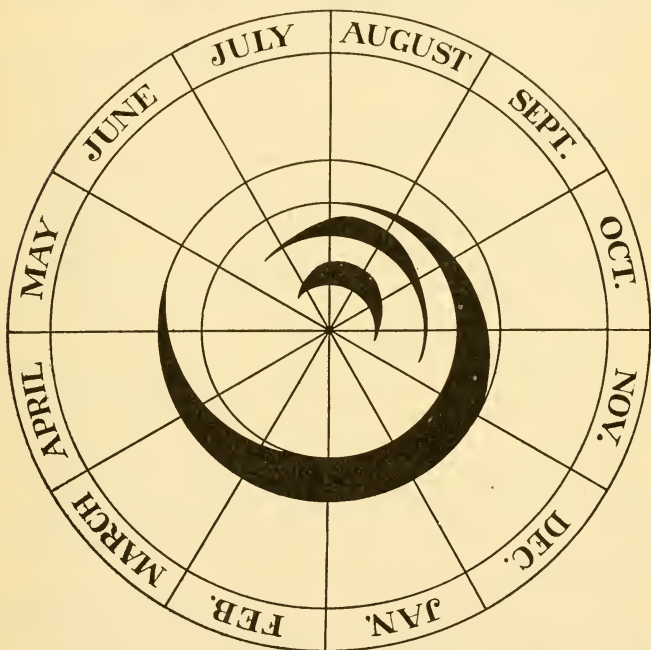


FIG. 10.—Diagram to illustrate annual life history: Innermost shaded crescent, active period of wandering radicicole larvæ; middle shaded crescent, period of development of the sexuparous migrant; shaded portion of outer circle, hibernation period of radicicole larvæ; unshaded portion of outer circle, period of active life on the roots.

completion of the final molt become mature insects. At first oval, they tend to become pyriform as they grow. The color, yellow, yellowish-green, or yellowish-brown, is dependent on the nature of the food. The length of the developmental period varies according to food and meteorological conditions. On succulent living roots the average period of larval development was found to be about 22 days (hibernant generation excluded), and the maximum and minimum respectively 36 and 10 days.

The winged form is produced from the middle of June until November. It is more abundant in the coastal districts than in the interior valleys. In their first two instars the larvæ of the winged form do not differ from the corresponding stages of the wingless form, but in the third and fourth stages they differ structurally, and in these stages are termed, respectively, prenymph and nymph. Both these forms are elongate in shape and are light greenish-yellow or yellowish-brown. The nymphs have two pairs of grayish-black wing pads. The winged insect is orange in color with grayish-black head and thorax and two pairs of scantily veined wings.

The nymphs transform in most instances near the surface of the soil and the winged migrants issue on the surface and fly about in the vineyard and neighboring regions.

The winged insects deposit eggs of two kinds, viz, male and female, and the insects which mature from these eggs are the true sexes. These forms are unable to take food, and under normal conditions mate upon reaching maturity and the female forthwith deposits a single egg under the bark of the vine. This egg hatches in spring and gives rise to a series of generations of gall-inhabiting and gall-making wingless aphids. A certain percentage of larvæ born in the galls, however, migrate to the roots before taking food, and in this way the species returns to the soil.

In California, under natural conditions, it is doubtful whether any sexes mature and still more doubtful whether any winter eggs hatch. Laboratory experiments indicate that the sexes mature in about 12 days.

In the late autumn, along with the nymphs are found curious forms intermediate in appearance between adult radicolles and nymphs. These are called intermediates or nymphicals. They are not abundant and all those whose progeny have been observed were parthenogenetic.

The diffusion of the phylloxera is effected in nature by the wandering newly hatched larvæ of the radicolles during summer and autumn. These pass from vine to vine, either on the surface of the soil or through subterranean cracks or pathways. They may also be borne by the wind or on vineyard material, such as picking boxes. Probably water is responsible for some diffusion in hilly or irrigated vineyards, and cultivating instruments by picking up pieces of infested roots may effect fresh infestations. The phylloxera is easily introduced into a vineyard or section by the practice of planting infested rooted vines to make up for cuttings which did not succeed in previous years.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.

PROFESSIONAL PAPER

October 20, 1920

FUMIGATION OF CITRUS PLANTS WITH
HYDROCYANIC ACID:
CONDITIONS INFLUENCING INJURY

By

R. S. WOGLUM, Entomologist, Tropical and Subtropical
Fruit Insect Investigations

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INTRODUCTION.

The important factors long known to modify damage to the fruit and foliage of citrus trees under orchard conditions of fumigation with hydrocyanic acid include temperature, moisture, light, and physiological condition of the plant. Of these, light appears to have more completely influenced the application of this gas than any other factor and early confined fumigation to a night practice. Coquillett (3),² the originator of orchard fumigation with hydrocyanic acid, found early in his studies that citrus trees were less liable to injury by this gas when treated at night than in daytime, and explained that this result was due to decomposition of the gas by light and heat into other gases more injurious to the plants. Gossard (7), working with citrus trees in Florida, stated that "mid-day fumigation can hardly be practiced." More recently Fernald, Tower, and Hooker (5), experimenting with cucumbers and tomatoes under glass, concluded that for such tender plants day fumigation, even in cloudy weather, is unsafe.

Literature treating of the causes of fumigation injury is confined almost exclusively to the consideration of conditions, physiological

¹ Resigned September 11, 1920.

² Reference is made by number (italic) to "Literature cited," p. 42.

as well as environmental, which prevail during the actual exposure of plants to the gas. The prefumigation and postfumigation environments have been given scant attention. The writer early in his fumigation studies observed types of injury not fully explainable by influences during the gas exposure, and subsequently it developed that certain factors must be considered, not only during but also before and after the gas treatment. Accordingly, a series of experiments was performed to determine the prefumigation and postfumigation influence, if any, of the two very important factors, heat and light. This paper presents the results of these experiments, and furthermore interprets the results in the light of field experience. In the discussion it has been found necessary to touch on other factors which also bear on the subject of fumigation injury.

THE EFFECT OF HYDROCYANIC ACID ON PLANTS.

The modification of plant injury by most external factors can be ascertained with sufficient accuracy and comprehensiveness to guide field work without attempting to determine the actual physiological action which occurs within the plant tissues when these are exposed to varying concentrations of hydrocyanic acid. Studies of the effect of this gas on plant metabolism have been made, however, and some very important papers have appeared setting forth the results of careful research on this subject. One of the earliest comprehensive papers confined to this subject was issued by Schroeder (17), in which he concluded, as the result of a long series of determinations on the effect of potassium cyanid on the fungus *Aspergillus niger*, that injury arises through paralysis of respiration, but that the reduced respiration is followed by complete recovery when the poison period does not last too long. Moore and Willaman (12), working with greenhouse plants, similarly conclude that the absorption of more or less hydrocyanic acid by plants results in a reduction of respiratory activity, and show that this inhibitory effect on respiration is due primarily to disturbance of the respiratory enzymes, oxidases, and catalase. Various other physiological effects resulting are the inhibition of photosynthesis and translocation of carbohydrates; also an increase in the permeability of the leaf septa.

Since the passage of gases takes place between the open air and the intercellular spaces of leaves through the stomata, it has been believed by most investigators of fumigation that hydrocyanic acid gains entrance into the tissues of fumigated plants through these openings. Researches by Moore (11) led to the conclusion that during fumigation hydrocyanic acid not only does enter plants through the stomata, if they are open, but also through the cuticle, depending upon its thickness and degree of cutinization. In a recent paper Clayton (1) emphasizes that the stomata seem to be the most important single factor in determining the amount of injury resulting from

hydrocyanic acid fumigation, although Stone (18) concluded from his investigations that susceptibility to injury is due more to the condition of the tissue, whether thin and tender or resistant, than to the open or closed condition of the stomata.

It has not been uncommon in California to hear practical fumigators state that plant injury during fumigation is due to impurities in the cyanid or sulphuric acid. One writer (23) has attributed injury to sulphuric-acid fumes given off during the gas generation and has discussed in great detail how such action is brought about. The work of Schroeder, Moore, and others disproves any conclusion that does not mention the cyanid gas itself as the cause of plant injury, and experiments by the writer (19) furnish further data in disproving these theories with reference to sulphuric acid. Furthermore, the recent wide use of high-purity liquid hydrocyanic acid, a material free of sulphuric acid, has been attended by the customary fruit and foliage injury.

DETAILS OF EXPERIMENTS.

Boxed seedling orange trees, pruned to several branches and from 1 to 2 feet in height, were grown beneath a canvas shelter which afforded protection from the midday sun. The foliage was dense and for the most part consisted of heavily cutinized leaves, except for the tender growth toward the top.

The gas-tight fumigatorium (Pl. I, A) in which the experiments were performed contained 100 cubic feet of space and was equipped with two large glass windows, which permitted the regulation of light conditions. Treatment in the shade signifies that both windows were fully exposed to diffused light. The temperature of the fumigatorium for any one experiment was uniform during the exposure, unless otherwise noted. All records were made in the Fahrenheit scale. Only high-grade commercial cyanids of 96 to 99 per cent purity were used. Potassium cyanid was used according to the 1-1-3 formula, or sodium cyanid according to the 1-1½-2 formula (19). The foliage in all cases was dry, unless otherwise noted. Check plants were used in all experiments and failure to refer to them signifies that the checks were in no way injured. The dosages in these experiments approximate those employed in orchard treatment in California. All plants in any one experiment were fumigated at the same time. Immediately after treatment they were removed from the fumigatorium and placed in different environments of temperature and light. Final notes on results were taken five to seven days after treatment. Shade signifies protection from the sun by a canvas shelter or a wooden building. Darkness means total exclusion of light. Moisture does not include atmospheric humidity. Injury as included in this paper should be interpreted as meaning damage to or death of tissues, so

that the effect is observable to the naked eye. Burned signifies severe injury amounting to the partial or total discoloration of numerous leaves, as by heat. Singed indicates slight burning, especially at the tips or edges of leaves.

Varying degrees of damage to the plants were indicated as follows in all experiments:

0—Plants entirely unaffected externally.

1—Some of the tenderest undeveloped leaves or tips of tender shoots at least slightly injured.

2—Tenderest tips with undeveloped leaves severely injured; fully grown tender leaves sometimes slightly affected; mature leaves uninjured.

3—Tender growth, including fully developed new leaves, destroyed; old leaves slightly affected.

4—Mature leaves in large numbers severely burned.

5—One-half to entire plant severely burned.

THE EFFECT ON PLANT INJURY OF TEMPERATURE, LIGHT, AND MOISTURE BEFORE FUMIGATION.

The fumigation of growing plants is usually conducted without regard to their environment prior to the gas exposure, barring the factor moisture relative to which a divergence of opinion exists. The experimental evidence presented in this paper bearing on prefumigation conditions draws attention not only to the influence of moisture but also to that of temperature and light. Data on the influence of these factors are brought out in experiments 1 to 9, inclusive, as well as in 11, 12, 14, 15, and 18, these latter experiments being discussed under the subject of postfumigation influences. Certain of these experiments, namely, 1, 2, 12, 14, 15, and 18, are of special value by reason of the number of postfumigation environments also included in each experiment.

EXPERIMENT 1.

Condition during fumigation, shade, 58°–60° F.

Dosage, 1½ ounces KCN.

Date, March 18, 1915, 8.45–9.45 a. m.

Plants in each test, 2; total, 30.

Remarks: Plants somewhat hardened.

Results.

Condition after fumigation.	Condition before fumigation.		
	Dark, 60° F.	Shade, 58° F.	Sun, 68° F. ¹
Dark, 60° F.....	1	1	3
Shade, 58° F.....	1	1	3
Dark, 86° F.....	2+	2+	5
Shade, 90° F.....	2+	2+	5
Sun, 72° F.....	3+	3+	5

¹ Plants in sunshine for 2 or 3 hours before fumigation. Maximum sun temperature for day, 77° F.



FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

- A*, Fumigatorium used in experimental work, showing interior arrangement.
B, Orchard citrus tree fumigated in the daytime and immediately afterward exposed to a hot sunshine; foliage completely destroyed. Other trees in the same grove, fumigated at an equal temperature but free from sunshine influence, were uninjured.

EXPERIMENT 2.

Condition during fumigation, shade, 67°–69° F.

Dosage, 1½ ounces KCN.

Date, March 15, 1915, 9.30–10.30 a. m.

Plants in each test, 2; total, 18.

Remarks: Plants somewhat hardened.

Results.

Condition after fumigation.	Condition before fumigation.		
	Dark, 55° F.	Shade, 67° F.	Sun, 75° F.
Dark, 55° F. ¹	1	1	3
Shade, 70° F. ²	1	1	3
Sun, 75° F. ³	2+	2+	5

¹ Temperature 55°–57° F. throughout day.

² Maximum shade temperature during day, 80° F., at 1.30 p. m.

³ Maximum sun temperature during day, 86° F., at 1.30 p. m.

EXPERIMENT 3.

Condition during fumigation, shade, 57°–58° F.

Condition after fumigation, shade, 59°–66° F., for 24-hour period.

Dosage, 1 ounce NaCN.

Date, September 28, 1915, 7.10–7.50 a. m.

Plants in each test, 5; total, 15.

Results.

Condition before fumigation.		
Shade, 56° F. ¹	Shade, 90° F. ²	Sun, 60° F. ³
2	2	2

¹ At cool temperature several hours before fumigation.

² At temperature 88°–90° F. for 1 hour before fumigation; previously at 56° F.

³ In sun for 1½ hours before fumigation.

EXPERIMENT 4.

Condition during fumigation, shade, 63° F.

Condition after fumigation, shade, 88°–90° F.

Dosage, 1 ounce NaCN.

Date, September 28, 1915, 9–9.40 a. m.

Plants in each test, 3; total, 12.

Results.

Condition before fumigation.			
Shade, 67° F., plants wet. ¹	Shade, 67° F., plants dry.	Sun, 72° F., plants wet. ¹	Sun, 72° F. plants dry.
3	3	3	4

¹ Plants thoroughly sprinkled with tap water before fumigation.

EXPERIMENT 5.

Condition during fumigation, dark, 64°-66° F.

Condition after fumigation, dark, 60° F.

Dosage, 1½ ounces KCN.

Date, May 17, 1916, 6.07-6.57 a. m.

Plants in each test, 7; total, 14.

Results.

Condition before fumigation.	
Dark, 64°-66° F.	Dark, 90°-102° F. ¹
2	2

¹ 5 hours before fumigation temperature raised from 70° to 90°-102° F.

EXPERIMENT 6.

Condition during fumigation, dark, 60° F.

Condition after fumigation, shade, 64° F.

Dosage, 1½ ounces KCN.

Date, March 30, 1916, 9.37-10.27 a. m.

Plants in each test, 5; total, 15.

Results.

Condition before fumigation.		
Sun, 67° F., plants dry.	Sun, 67° F., plants wet, water temper- ature, 58° F.	Sun, 67° F., plants wet, water temper- ature, 86° F.
1	1	1

EXPERIMENT 7.

Condition during fumigation, dark, 72°-73° F.

Condition after fumigation, shade, 65° F.

Dosage, 1 ounce NaCN.

Date, October 7, 1915, 12.10-12.50 p. m.

Plants in each test, 5; total, 15.

Remarks: Plants exposed to the sunshine for several hours, then wet thoroughly immediately before fumigation.

Results.

Condition before fumigation.		
Sun, 80° F., plants dry.	Sun, 80° F., plants wet, water temper- ature, 64° F.	Sun, 80° F., plants wet, water temper- ature, 96° F.
4	3	4

All dry plants had the mature foliage quite severely burned, while only 3 of the 5 hot-water-treated plants were equally severely affected. None of the plants treated with cold water were as severely injured as where dry.

EXPERIMENT 8.

Condition during fumigation, dark, 62° F.

Condition after fumigation, shade, 67° F.

Dosage, 1½ ounces KCN.

Date, May 17, 1916, 9.50-10.40 a. m.

Plants in each test, 5; total, 15.

Results.

Condition before fumigation.		
Shade, 65° F., plants dry.	Shade, 65° F., plants wet, water temperature, 68° F.	Shade, 65° F., plants wet, water temperature, 100° F.
2	2	2

EXPERIMENT 9.

Condition during fumigation, dark, 62° F.

Condition after fumigation, sunshine, 74° F.

Dosage, 1½ ounces KCN.

Date, March 30, 1916, 10.57-11.47 a. m.

Plants in each test, 5; total, 10.

Results.

Condition before fumigation.	
Shade, 66° F., dry.	Shade, 66° F., wet.
4	4

DARKNESS AND SHADE.

In experiment 1 ten citrus plants in the dark at a temperature of 60° F. and ten in the shade at approximately the same temperature (58° F.) were fumigated at the same time. After treatment they were so divided that plants from each prefumigation condition were placed under five distinct postfumigation environments, each to include two plants from the darkness and two from the shade. No difference in degree of injury could be detected between the plants from prefumigation shade and those from prefumigation darkness in any of the five postfumigation conditions. Equivalent results are presented in experiment 12 between the series of plants in prefumigation shade and prefumigation darkness at 60° F. These results would appear to indicate that neither darkness nor diffused light before fumigation in any way influences the degree of injury to citrus plants from treatment with hydrocyanic acid.

TEMPERATURE.

The relation of temperature before fumigation to plant injury is brought out in experiments 2, 3, 5, 14, 15, and 18. In experiment 3 it is seen that plants at a shade temperature of 90° F. before fumigation were no more severely injured than others at a temperature of 56° F. Practically identical results occurred in experiment 5, where the prefumigation conditions were darkness at temperatures of 64°–66° F. and 90°–102° F., and in both cases merely the tenderest growth was slightly injured. Experiments 3 and 5 were performed at cool temperatures, and the postfumigation environment was cool. On the other hand, experiment 15, which was conducted at the high temperatures of 86°–91° F., developed no difference in injury between plants at prefumigation temperatures of 62° and 90° F.

In experiments 14 and 18 most of the plants showed no apparent difference in injury attributable to temperature before exposure. A few plants, however, did show slightly greater injury than others under similar postfumigation conditions and in these cases all the more severely injured plants were under the highest prefumigation temperatures (80° and 76° F., respectively). These two experiments were performed at comparatively high temperatures (85° to 92° F.).

It would appear from these experiments, therefore, that where plants are in shade or darkness the temperature immediately previous to fumigation has little influence on the resultant plant injury. Sometimes, however, a difference in plant injury apparently due to heat influences develops, and in such cases the greatest injury appears on those plants subject to the highest prefumigation temperatures. In the experiments in this paper the prefumigation temperatures ranged between 56° and 102° F. Within these limits there was little or no difference in injury where the fumigation and postfumigation temperatures were both below 70° F. However, slightly more increased injury did occur at the prefumigation temperatures of 76° and 80° F. than at 56° F. in two experiments in which the actual fumigation temperature was about 85° F. This would indicate the advisability of keeping plants at a cool temperature prior to fumigation in case the fumigation and postfumigation environments are hot. If the fumigation and postfumigation temperatures are cool a comparatively high prefumigation temperature appears to have little more effect on the results than a cool temperature.

SUNSHINE.

The influence of sunshine on plants before fumigation is shown by the results of experiments 1 to 4, 12, 14, 15, and 18. In experiment 1 this influence previous to the gas treatment contrasts sharply with that of diffused light or darkness. Sun and shade exposed plants under cool temperature conditions were fumigated at the same time and on removal from the fumigatorium were placed under five dif-

ferent conditions. In each of the five conditions the prefumigation sun-exposed plants developed decidedly greater injury than those that were in shade before treatment. The results of experiment 18, in which plants were exposed to a hot sunshine (83° F.) immediately before fumigation and fumigated at a high temperature, show all sun-exposed plants killed regardless of the postfumigation conditions; yet others in the shade at approximately the same prefumigation temperature (76° F.) and placed at a temperature of 56° F. after the treatment had only the very tenderest foliage singed. The effect of prefumigation sunshine is not so conclusively brought out in the other experiments, but, with the exception of No. 3, it appears to have intensified the injury in at least a few of the trees treated. Experiment 3 alone shows no difference between plants in the shade and those in the sunshine previous to fumigation. It is noted in this case that the sunshine temperature was 60° F. and the fumigation and postfumigation conditions were equally cool, all three being ideal for exposure to cyanid gas.

A comparative study of the temperature before and after treatment shows that the effect of prefumigation sunshine is modified by the degree of heat present at these different times. For instance, in experiment 3 where the sunshine appeared not to affect the degree of injury more than the shade, all fumigation conditions, the prefumigation, postfumigation, and actual fumigation, approximated 60° F. On the other hand, experiment 2, which was performed with the same type of plants, the same dosage, and at approximately the same temperature, exhibited a decided difference in injury between the prefumigation shade and sunshine-exposed plants, the injury in the latter being greater than for experiment 3. It is noted that the sun temperature in experiment 2 was 75° F., whereas in experiment 3 it was 60° F., which shows that the degree of injury attributable to sunshine increased with the increased temperature. Thus a hot sunshine before fumigation is more to be avoided than a cool sunshine.

In conclusion it can be stated that the experimental evidence in this paper appears to show that sunshine coming in contact with citrus plants before fumigation tends to produce greater injury than where plants are in the shade or darkness; that sunshine accompanied by a high temperature is more injurious than if accompanied by a low temperature; that the degree of injury is modified by the postfumigation conditions, greater injury developing at high temperatures than at low temperatures; that the most critical environment is to subject plants exposed to a hot sunshine before fumigation to a hot sunshine after fumigation; finally, that a high temperature during fumigation probably increases the injury of prefumigation sunshine-exposed plants over that taking place at a low temperature.

MOISTURE.

The effect of moisture on fumigated citrus trees is shown in experiments 4, 6 to 9, and 11, in which varied prefumigation conditions occur. In Nos. 4, 8, 9, and 11 a number of plants in the shade at temperatures between 60° and 68° F. were drenched with water before they were placed in the fumigatorium with others having perfectly dry foliage, and were then immediately subjected to hydrocyanic-acid gas. Thirty-seven plants in all were used in these four experiments and in no case was there any apparent difference in injury between the wet and the dry plants, even though a number of the trees had some very tender foliage.

In experiments 4, 6, and 7 plants were exposed to prefumigation sunshine at temperatures ranging from 67° to 80° F. Immediately before fumigation a part was drenched with water and afterwards fumigated with others having perfectly dry foliage. Experiment 6 exhibits the same degree of injury for the wet plants as for the dry, a condition which holds true whether the water used in the treatment was 58° or 86° F. In experiment 4 the dry plants were slightly more severely injured than the wet, quite the contrary to what would be expected, and in fact to what is shown by Moore (11) to take place in the case of tender greenhouse plants. In experiment 7 the dry plants were likewise more severely injured than those treated with cool water, although where wet with warm water the injury was equal. While these two experiments are insufficient in themselves to prove definitely that plants subjected to a hot sunshine before fumigation are more severely injured when dry than when wet it at least indicates that the wetting of such plants can, in some cases at least, reduce the degree of injury to an extent. In this connection it should be noted that the reduction of injury to the wet plants occurred where the water used was at a temperature considerably lower than that of the sunshine. Water at a temperature equal to or higher than the sun temperature did not appear to influence the degree of injury over that normal to dry plants.

In conclusion it may be stated that water on citrus plants appears in no way to affect the degree of injury, if the plants are subjected to shade or darkness before treatment; if, however, plants are in the direct sunshine before treatment, water appears to reduce the injury slightly, at least in some cases where the temperature of the water is below that of the sunshine.

THE EFFECT ON PLANT INJURY OF TEMPERATURE, LIGHT, AND MOISTURE AFTER FUMIGATION.

Fumigation with hydrocyanic acid is usually considered completed with the separation of the treated plants from exposure to the gas. Little or no attention has been given to the postfumigation environ-

ment. That this environment may modify the degree of plant injury is shown in the following experiments, which indicate the influence of different light intensities and of different temperatures on citrus plants immediately after fumigation with hydrocyanic acid. These experiments were performed, some in darkness and some in the shade, at temperatures ranging from 60° to 91° F. All plants in each experiment were fumigated at the same time, part being placed immediately after treatment in direct sunshine, part in the shade, and, excepting Nos. 11, 13, and 19, part in darkness. An effort was made in several experiments to have the shade temperature approximate that of the sunshine, thereby eliminating consideration of the heat factor and furnishing an exact basis for determining the influence of the sun's direct rays, a factor of special consideration. Most of the experiments also contain postfumigation environments of shade or darkness at decidedly cooler temperatures than those of sunshine, and thus furnish data for study of comparative temperature influences. Four experiments, Nos. 12, 14, 15, and 18, include plants under three different prefumigation environments, each set of which was subjected to either four or five different postfumigation conditions. Such experiments offer a wide range of data on the influence of various prefumigation as well as postfumigation factors.

EXPERIMENT 10.

Condition during fumigation, dark, 64° F.

Condition before fumigation, dark, 64° F.

Dosage, 1 ounce NaCN.

Date, September 22, 1915, 7-7.40 a. m.

Plants in each test, 4; total, 20.

Results.

Condition after fumigation.				
Dark, 65° F. ¹	Shade, 65° F. ¹	Dark, 79° F. ²	Shade, 79° F. ²	Sun, 79° F. ²
2	2	2	2	4

¹ At cool temperatures throughout the day.

² At equal temperatures throughout the day. Maximum 102° F. at 2 p. m.

EXPERIMENT 11.

Condition during fumigation, dark, 61° F.

Condition before fumigation, shade, 61° F.

Dosage, 1 ounce KCN.

Date, June 17, 1914, 8.15-9 a. m.

Plants in each test, 3; total, 12.

Remarks: Condition of plants comparatively tender. All at equal temperatures throughout the day after fumigation. Maximum 83° F. at 2 p. m. Plants wet immediately before fumigation.

Results.

	Condition after fumigation.	
	Shade, 65° F.	Sun, 65° F.
Foliage drenched with water.....	2	4
Foliage dry.....	2	4

EXPERIMENT 12.

Condition during fumigation, dark, 64°-65° F.

Dosage, 1½ ounces KCN.

Date, March 18, 1915, 10.50-11.50 a. m.

Plants in each test, 2; total, 30.

Remarks: Fumigatorium contained ice to maintain a low temperature. This absorbed much gas.

Results.

Condition before fumigation.	Condition after fumigation.				
	Dark, 60° F.	Shade, 60° F.	Dark, 90° F. ¹	Shade, 88° F. ¹	Sun, 75° F. ²
Dark, 60° F.....	2	2	3	3	3
Shade, 60° F.....	2	2	3	3	3
Sun, 73° F.....	2	2	4	4	4

¹ Temperature maintained 4 hours after treatment.

² Maximum temperature for day, 77° F.

EXPERIMENT 13.

Condition during fumigation, dark 66°-68° F.

Condition before fumigation, shade, 66° F.

Dosage, 1 ounce NaCN.

Date, November 17, 1917, 9-10 a. m.

Plants in each test, 4; total, 12.

Remarks: Plant foliage tender.

Results.

Condition after fumigation.		
Shade, 68° F.	Shade, 79° F. ¹	Sun, 79° F. ¹
2	2	5

¹ At equal temperatures throughout the day. Maximum 98° F. at 2 p. m.

All foliage on plants in the sunshine was destroyed, while those in the shade exhibited injury only to the tenderest growth.

EXPERIMENT 14.

Condition during fumigation, dark, 91°–92° F.

Dosage, 1½ ounces KCN.

Date, March 15, 1915, 1.30–2.30 p. m.

Plants in each test, 2; total, 22.

Remarks: Plants were in a somewhat resistant condition. Temperature of the fumigatorium 80° F. when plants entered, being raised immediately to 90°–91° F. before fumigation, and thus maintained throughout the exposure.

Results.

Condition before fumigation.	Condition after fumigation.			
	Dark, 56° F. ¹	Shade, 80° F. ²	Shade, 90° F. ³	Sun, 85° F. ⁴
Dark, 56° F.	2	3	3+	-----
Shade, 80° F.	3	3+	3+	4
Sun, 86° F.	3	4	4	5

¹ Temperature uniform throughout day.

² Held at sun temperature.

³ Temperature 85°–90° F. maintained for 3 hours after treatment.

⁴ Temperature dropped to 75° F. 3 hours after exposure.

EXPERIMENT 15.

Condition during fumigation, dark, 86°–91° F.

Dosage, 1½ ounces KCN.

Date, March 18, 1915, 12.35–1.35 p. m.

Plants in each test, 2; total, 30.

Remarks: Growth as in experiment 14. Temperature of fumigatorium 73° F. when plants entered, being raised immediately to and maintained at 86°–91° F. during fumigation.

Results.

Condition before fumigation.	Condition after fumigation.				
	Dark, 63° F. ¹	Shade, 63° F. ¹	Dark, 91° F. ²	Shade, 89° F. ²	Sun, 77° F. ³
Dark, 62° F.	3	3	4	4	4
Dark, 90° F.	3	3	4	4	4
Sun, 77° F.	4	4	4	4	4

¹ Maximum temperature for 24 hours after treatment, 65° F.

² Temperature 86°–91° F. maintained for 3 hours after treatment.

³ Temperature 3 hours after treatment, 69° F. Slight haze developed during afternoon and at 4.45 p. m. completely obliterated the sun.

EXPERIMENT 16.

Condition during fumigation, shade, 61°–63° F.

Condition before fumigation, dark, 60° F.

Dosage, 1 ounce NaCN.

Date, September 22, 1915, 6.10–6.50 a. m.

Plants in each test, 4; total, 20.

Results.

Condition after fumigation.				
Dark, 65° F. ¹	Shade, 64° F. ¹	Dark, 73° F. ²	Shade, 70° F. ²	Sun 73° F. ²
2	2	2	2	4

¹ At cool temperatures throughout day.

² At equal temperatures throughout the day; maximum 102° F. at 2 p. m.

EXPERIMENT 17.

Condition during fumigation, shade, 60°–62° F.

Condition before fumigation, dark, 64° F.

Dosage, 1 ounce NaCN.

Date, September 21, 1915, 6.50–7.35 a. m.

Plants in each test, 5; total, 20.

Results.

Condition after fumigation.			
Dark, 64° F. ¹	Dark, 80° F. ²	Shade, 70° F. ³	Sun, 71° F. ³
2	2	2	4

¹ Temperature 64°–68° F. throughout the day.

² Temperature 80°–91° F. during the day.

³ Temperatures equal throughout the day; maximum 94° F. at 1 p. m.

EXPERIMENT 18.

Condition during fumigation, shade, 85°–89° F.

Dosage, 1½ ounces KCN.

Date, March 15, 1915, 11.20–12.20 p. m.

Plants in each test, 2; total, 24.

Remarks: Growth as in experiment 14. Plants placed in fumigatorium at temperature 70°–75° F. which was immediately raised to and maintained at 85°–89° F. during fumigation.

Results.

Condition before fumigation.	Condition after fumigation.			
	Dark, 56° F. ¹	Shade, 79° F. ²	Shade, 90° F. ³	Sun, 85° F. ⁴
Dark, 56° F.	2	3	3	4
Shade, 76° F.	2	3	4	5
Sun, 83° F.	5	5	5	5

¹ Temperature practically uniform for day following treatment.

² Maximum temperature, 80° F.

³ Temperature, 90° F. maintained for 4 hours.

⁴ Maximum temperature, 86° F. at 1.30 p. m.

EXPERIMENT 19.

Condition during fumigation, shade, 78°–80° F.

Condition before fumigation, shade, 76° F.

Dosage, 1½ ounces NaCN.

Date, November 2, 1917, 9.20–10.20 a. m.

Plants in each test, 2; total, 6.

Remarks: Plants hardened from growth in open.

Results.

Condition after fumigation.		
Shade, 74° F. ¹	Shade, 87° F. ²	Sun, 87° F. ²
2	2	5

¹ Maximum temperature, 80° F. at 2 p. m.

² Maximum temperature, 93° F. at 1 p. m.

DARKNESS AND SHADE.

The effect on plant injury of shade and darkness after fumigation is well illustrated by experiments 10, 12, 15, and 16 which are arranged in Table I for comparison of these influences.

TABLE I.—*Comparative effects of diffused light and darkness on plants after fumigation with hydrocyanic acid.*

	Postfumigation temperatures.								
	Experiment 10.		Experiment 12.			Experiment 15.		Experiment 16.	
	65° F.	79° F.	60° F. ¹	88°-90° F. ²		63° F. ²	89°-91° F. ¹	64°-65° F.	70°-73° F.
Darkness.....	2	2	2	3	4	3	4	2	2
Shade.....	2	2	2	3	4	3	4	2	2

¹ Includes 3 fumigation conditions.

² Includes 2 fumigation conditions.

An examination of this table shows that in none of the several tests included is there any difference in injury between the plants placed in darkness and those placed in the shade following fumigation. This condition holds equally true at the minimum post-fumigation temperature of 60° F. or the maximum of 91° F. for these experiments. Likewise this situation does not appear to be altered by the temperature of fumigation, for experiments 10, 12, and 16 were performed at 61°-64° F. while experiment 15 was carried on at 86°-91° F.

SUNSHINE.

The influence of sunshine on citrus plants immediately after fumigation is clearly developed in experiments 10 to 19. Eight of these 10 experiments show a decidedly greater injury to the plants placed in the sunshine after fumigation than to those placed in either the shade or darkness at equivalent temperatures. This condition is brought out in Table II.

TABLE II.—*Comparative degree of injury between plants placed in the sunshine and those placed in the shade or darkness following fumigation.*

	Postfumigation temperatures.										
	Exp. 10.	Exp. 11.	Exp. 13.	Exp. 14. ¹		Exp. 16.	Exp. 17.	Exp. 18. ²			Exp. 19.
	79° F.	65° F.	79° F.	80° F.	85° F.	70°- 73° F.	70°- 71° F.	85°-90° F.			87° F.
Darkness.....	2	-----	-----	-----	-----	2	-----	-----	-----	-----	-----
Shade.....	2	2	2	3+	4	2	2	3	4	5	2
Sunshine.....	4	4	5	4	5	4	4	4	5	5	5

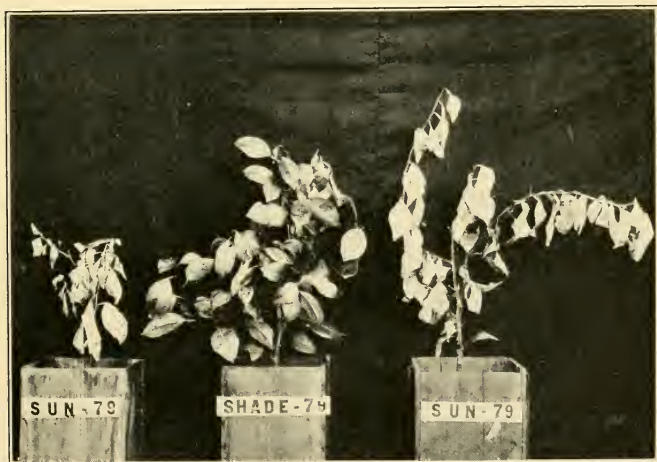
¹ Experiment consisting of two distinct parts.

² Experiment consisting of three distinct parts.

An examination of this table shows that a dosage which slightly injures merely the tenderest growth of plants placed either in the shade or darkness after fumigation may result in severe burning of even the old, resistant leaves if the treated plants are exposed to sunlight (Pl. II, A), while in extreme cases complete defoliation follows, as happened in experiments 13 and 19. Increased injury due to sunshine was apparent even at as low a sun temperature as 65° F., which was the minimum experienced (experiment 11). The plants in this case were comparatively tender, and this condition naturally invited greater injury than would have been the case with more resistant foliage. A study of the data presented in these experiments would appear to indicate that, all other conditions being the same, injury increases more or less directly with the sun temperature. The plants in experiment 11 were somewhat tender yet the degree of injury in the case of those exposed to the sunshine (65° F.) was less than to the plants in a hardened condition in experiment 19, in which the postfumigation sunshine temperature was 87° F. In this latter experiment the hardened or resistant growth of plants placed in the sunshine was almost completely destroyed, although plants placed in the shade at the same temperature merely had the tenderest growth injured (Pl. II, A). This would indicate that sunshine at such a high temperature is more injurious than sunshine at a low temperature; in short, that the toxic action of hydrocyanic acid on fumigated plants subjected to sunshine increases with the sun's intensity.

Turning to experiment 12 it is seen that the sun-exposed plants were no more injured than those in the shade at a slightly higher temperature. It so happened that in this experiment the fumigatorium contained a piece of ice which had been used to maintain a low temperature prior to the treatment. This ice absorbed gas with the result that the strength of the gas was greatly reduced at the end of the hour's exposure. A conclusion to be deduced from this experiment is that plants exposed either to a strong gas for a short period or to a dilute gas for a longer period before being placed in the sunshine are much less injured by fumigation than plants exposed to a gas which maintains its proper strength throughout the period of an hour's exposure, as in the other nine experiments. Data in support of this statement are found elsewhere in this paper and, furthermore, are supported by other experiments performed by the author but not included in this article.

The relation of the temperature of fumigation to injury to plants subsequently exposed to sunshine is not well shown by the experimental data presented. Plants in experiments 10, 11, 13, 16, and 17 were fumigated at comparatively cool temperatures (60°–68° F.), yet the injury was about as severe to those plants subsequently placed in the sunshine as to those under similar postfumigation conditions



FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A, Comparative effect of hot sunshine and shade, after fumigation, on citrus plants with resistant foliage. Immediately following the treatment two plants were placed in direct sunlight and one in the shade, at 87° F., and held at parallel temperatures throughout the remainder of the day. It is noted that leaves in the sun-exposed plants have abscised at the base of the blade. *B*, Citrus plants with tender foliage which were exposed immediately after fumigation to the sun or shade at 79° F. The plant in the shade had merely the tender tips injured. All leaves and petioles of the sun-exposed plants were completely burned and eling without abscission.

in experiments 14, 15, and 18, which were fumigated at temperatures ranging from 86° to 92° F. This would appear to indicate that the temperature of fumigation within the limits of those experiments, 60° and 92° F., has little if any modifying influence on the resulting degree of injury to plants subjected to the sunshine after treatment. It happens, however, that the prefumigation or postfumigation conditions in experiments 14, 15, and 18 were exactly comparable to those in none of the other experiments mentioned. Although section 1 of experiment 15 approximates experiment 10 as to prefumigation and postfumigation conditions, it is seen that the maximum sun temperature for the day in experiment 15 was 77° F., whereas in experiment 10 it was 102° F. Therefore, definite conclusions regarding the influence of the temperature of fumigation on plants subsequently placed in sunshine can not be drawn until there is further experimental evidence bearing on this subject.

The effect of postfumigation sunshine on plant injury appears to be modified to a certain degree by the prefumigation light condition. This is well shown by experiments 2 and 14, in which the damage to the plants under postfumigation sunshine is greater in the case of plants exposed to prefumigation sunshine than to plants in prefumigation shade at a comparable temperature. It is probable that the prefumigation temperature modifies to some degree the effect of postfumigation sunshine, but this point is not conclusively proved in this paper.

TEMPERATURE.

The importance of the temperature to which plants are subjected after fumigation as a factor bearing on plant injury is brought out by the experimental data presented in experiments 1, and 10 to 19. It is shown in experiment 12 that fumigated plants placed immediately after treatment under a shade temperature of 88° F. or a darkness temperature of 90° F. are slightly more injured than those placed at a temperature of 60° F. A like condition is presented in experiment 15 between postfumigation temperatures of 63° F. and 89° or 91° F. Experiments 1, 14, and 18 also show slightly increased injury due to higher postfumigation temperatures in the shade or darkness. On the other hand, each experiment of numbers 2, 10, 13, 16, and 17 shows the same degree of injury for plants subjected to different temperatures of shade and darkness following fumigation. An examination of the details of these experiments, however, brings out a significant difference between the two groups. In the set of experiments (2, 10, 13, 16, and 17) in which there was no apparent difference in injury due to the different postfumigation temperatures it is seen that the difference between the high and low temperatures in any one experiment varies from 9° in experiment 16 to a maximum of 16° in experiment 17; furthermore, that the maximum postfumigation

temperature for these five experiments is 80° F., a maximum only a few degrees higher than the limit of optimum temperatures established for field fumigation. On the other hand, in the set of experiments (1, 12, 14, 15, and 18) which shows a difference in injury between plants submitted to high and those submitted to low postfumigation temperatures, the range is from a minimum of 23° in experiment 18 to a maximum of 34° in experiment 14. In short, the minimum range in the last set of experiments is 7° higher than the maximum range in the first set which developed no difference of injury; furthermore, the maximum postfumigation temperatures are higher, ranging from 86° to 90° F., except in experiments 14 and 18, in which they are 80° and 79° F. respectively. Another consideration of special importance is the temperature of fumigation, which in the first set of experiments ranged from 60° to 69° F., whereas in three of the five experiments of the set which developed differences in injury the fumigation temperature ranged from 85° to 92° F. Two of the experiments in this last set, namely, 1 and 12, were performed at temperatures of 60° and 64° F. In these two experiments, however, the postfumigation temperatures were very high, 86° and 90° F., and the range between the cold and hot postfumigation temperatures was from 26° to 30°.

The general conclusion to be drawn from these experiments is that the postfumigation temperature exerts an influence on the degree of injury, especially at temperatures of 80° F. or above. The effect of such high temperatures is modified by the temperature of fumigation; for instance, a high postfumigation temperature preceded by a high fumigation temperature is more destructive to plant tissue than a high postfumigation temperature preceded by a low fumigation temperature. In fact, as is well shown in experiments 10 and 15, it is possible to subject plants treated at such low temperatures as 60° to 65° F. to moderately high postfumigation temperatures (79° and 80° F.) without any more injury than at the lower temperatures of 64° or 65° F. The postfumigation temperature of shade or darkness is so closely related to the actual fumigation temperature in modifying plant injury that it is important to take cognizance of each in plant treatment. The influence of temperature on plants subjected to sunshine following treatment has been discussed under the heading "Sunshine." To avoid injury, or at least to reduce the possibility of damage to the lowest degree, the data presented in this paper appear to indicate that after fumigation plants should be placed at temperatures below 80° F. The exact number of degrees the optimum falls below 80° will depend on the prefumigation and fumigation temperatures. When these are ideal the maximum optimum apparently approximates 80° F., but if they are not the optimum is lowered a few degrees.

THE INFLUENCE OF SUNSHINE AT VARYING PERIODS AFTER FUMIGATION.

While experiments 10 to 19 clearly demonstrate the influence of sunshine on plants exposed immediately after fumigation, the following four experiments set forth the effect of this factor where plants are placed in the sunshine four hours or more after treatment.

EXPERIMENT 20.

Condition during fumigation, shade, 62°-65° F.

Condition before fumigation, shade, 66° F.

Dosage, 1 ounce NaCN.

Date, September 21, 1915, 8-8.45 a. m.

Plants in each test, 3; total, 21.

Results.

Condition after fumigation.						
Shade, 79° F. ¹	Shade, 90° F. ²	Sun, 76° F., exposed imme- diately.	Sun, 79° F., exposed after 30 minutes. ³	Sun, 80° F., exposed after 1 hour. ³	Sun, 84° F., exposed after 2 hours. ³	Sun, 88° F., exposed after 3 hours. ³
2	2	5	4	4	3	2

¹ Equal to sun temperature throughout the day.

² Temperature held at 85°-91° F. all day.

³ Plants removed from fumigatorium to shade (temperature approximately 70° F.) until placed in sunshine. Maximum sun temperature 94° F. at 1 p. m.

EXPERIMENT 21.

Condition during fumigation, dark, 58°-60° F.

Condition before fumigation, shade 60° F.

Dosage, 1½ ounces KCN.

Date, March 21, 1915, 8-9 a. m.

Plants in each test, 3; total, 27.

Remarks: Plants were in a somewhat resistant condition.

Results.

Condition after fumigation.								
Shade, 64° F. ¹	Shade, 90°-97° F. ²	Sun, 77° F., exposed at once. ³	Sun, 77° F., exposed after 5 minutes. ³	Sun, 77° F., exposed after 15 minutes. ³	Sun, 79° F., exposed after 30 minutes. ³	Sun, 79° F., exposed after 1 hour. ³	Sun, 82° F., exposed after 2 hours. ³	Sun, 84° F., exposed after 4 hours. ³
1	4	4	4	4	4	4	1	1

¹ Temperature 64°-70° F. all day.

² Temperature fluctuated 90°-97° F. all day.

³ Plants held in shade at 61°-62° F. between time of removal from fumigatorium and placement in sunshine. Maximum sun temperature 85° F. at 1 p. m.

EXPERIMENT 22.

Condition during fumigation, shade, 58° F.

Condition before fumigation, shade, 59° F.

Dosage, 1½ ounces KCN.

Date, March 30, 1916, 8.15-9.05 a. m.

Plants in each test, 3; total, 18.

Remarks: Plants in a slightly resistant condition. Maximum sun temperature 76° F. Plants were removed from fumigatorium to cool shade for the period elapsing before placement into sunshine.

Results.

Condition after fumigation.					
Shade, 60° F.	Sun, 66° F., exposed at once.	Sun, 67° F., exposed after 30 minutes.	Sun, 68° F., exposed after 1 hour.	Sun, 72° F., exposed after 2 hours.	Sun, 74° F., exposed after 3 hours.
1	4	3	3	3	2

EXPERIMENT 23.

Condition during fumigation, shade, 65° F.

Condition before fumigation, shade, 68° F.

Dosage, 1½ ounces KCN.

Date, March 30, 1916, 12.03-12.53 p. m.

Plants in each test, 3; total, 18.

Remarks: Plants in a slightly resistant condition. They were removed from fumigatorium to cool shade for period elapsing before placement into sunshine. Maximum sun temperature, 76° F.

Results.

Condition after fumigation.					
Shade, 71° F.	Sun, 76° F., exposed at once.	Sun, 77° F., exposed after 30 minutes.	Sun, 76° F., exposed after 1 hour.	Sun, 74° F., exposed after 2 hours.	Sun, 71° F., exposed after 3 hours.
1	4	3	3	2	1

In each of these four experiments all plants were removed from the fumigatorium immediately after exposure, part being placed at once in the sun while the remainder were held in the shade. Those plants which were exposed to the sunshine at different periods following fumigation were held in the shade at a cool temperature (60° to 70° F.) between the time of their removal from the fumigatorium and placement in the sunshine. Some plants were held continuously in the shade at certain temperatures as a check on the injury attributable to direct sunshine.

It is seen by an examination of experiment 20 that the dosage used merely injured the very tenderest growth where plants were placed

under shade temperatures of 79° and 90° F. immediately after the exposure, although plants exposed to the sunshine (76° F.) at the same time had almost all foliage, both tender and resistant, destroyed. Plants held in the shade for 30 minutes and one hour, respectively, after treatment and then subjected to sunshine at temperatures of 79° and 80° F. were about equally affected and this amounted to having a large part of the old resistant foliage destroyed. The injury, however, was noticeably less than where the plants had been exposed immediately after the treatment. Plants withheld for a period of two hours before placement in the direct sunshine had the tender growth destroyed and a few old leaves slightly affected, while plants held three hours before placement in the sunshine were no more

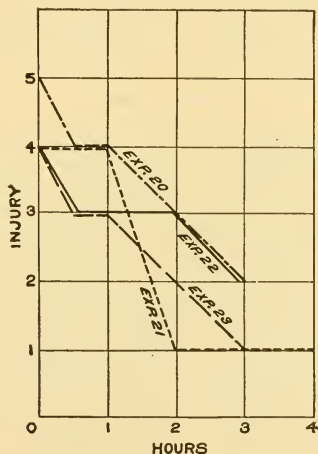


FIG. 1.—Graph showing relation of plant injury to exposure to sunshine at different periods after fumigation.

injured than those placed in the shade, only the tenderest growth being burned in either case.

The results of this experiment are fully corroborated by both experiments 22 and 23, and in part by experiment 21. In number 21, however, although the results agree with those in the other three experiments in showing that sunshine increases the toxic action of hydrocyanic-acid gas to the plant for a period of fully one hour after exposure, it differs somewhat in that the full effect of the sun is shown for one hour after which its influence quickly disappears.

The evidence presented in these four experiments shows that sunshine affects the degree of injury to fumigated citrus trees usually for a period of at least two hours after treatment where dosages equivalent to those used in these experiments are given to growing plants; that the greatest injury follows exposure to sunshine imme-

diately or within a few minutes after the fumigation; that the influence of sunshine which first reaches plants 30 minutes after treatment is practically the same as that of sunshine which first reaches the plants one hour after fumigation, and in all cases is severe; that the effect when plants are withheld for three hours before exposure to sunshine is seldom greater than where they are kept in the shade or in darkness at equal temperatures; in short, that sunshine appears to affect fumigated plants little or not at all at periods exceeding three hours after treatment.

THE EFFECT ON PLANT INJURY OF TEMPERATURE, LIGHT, AND MOISTURE DURING FUMIGATION.

The effect of certain weather conditions during the period when plants are actually exposed to hydrocyanic acid is brought out clearly in experiments 1 to 27.

DARKNESS AND SHADE.

The comparative influence on plant injury of shade to darkness during fumigation is shown by certain experiments, of which numbers 10 and 16 are especially representative. In these experiments are found practically identical prefumigation and postfumigation conditions, and the actual fumigation environments differ only in that No. 10 was performed in the dark while No. 16 was carried on in diffused light. The results of these experiments indicate no difference in degree of injury between plants fumigated in the shade and those fumigated in darkness. Experiments 5 and 17 contain a series of plants which present results corroborating those shown in experiments 10 and 16. A careful comparison of other experiments given in this paper supports the conclusion that citrus plants are as safely fumigated in diffused light as in total darkness.

SUNSHINE.

No experiments were performed in which plants were exposed to sunshine during treatment, but in consideration of the results previously shown where plants exposed to the sunshine immediately after fumigation developed very much more severe injury than others in the shade or dark at equal temperatures, it would appear that at least equally severe injury would develop from sunshine during the actual treatment. Factors which bring about injury from exposure to sunshine after fumigation would appear to be present in at least equal force in exposure to sunshine during actual treatment. Sunshine exposure during actual treatment would be possible only under glass, and in such cases would be accompanied by a temperature greater than that of the outside air.

MOISTURE.

Experiments 4, 6 to 9, and 11, were performed with both dry and wet plants. A comparison of results of these experiments has been presented under the paragraph treating on prefumigation influences. It was found that moisture on plants in prefumigation shade or darkness in no way affects the results where the fumigation is performed in shade or darkness. However, where plants were in sunshine before fumigation it appeared that a wetting with cool water tended to reduce the injury below that normal to dry plants.

TEMPERATURE.

Temperature is a factor of much concern during actual fumigation, and has already been discussed in this paper. Its influence is so modified by the prefumigation and postfumigation temperature and light conditions that it is necessary to pay full attention to these two latter environments in determining the temperature of safety during actual gas exposure. The experiments included in this paper in which plants were at no time exposed to the sunshine, and in which the prefumigation and postfumigation temperatures were within the range of optimum heat conditions, exhibited very little injury where plants were fumigated at temperatures below 80° F. In some experiments in which the temperature of fumigation exceeded 80° the injury appeared to be little if any more severe than at lower temperatures of fumigation, provided the prefumigation and postfumigation temperatures were both low; in other experiments the injury appeared to be greater at the higher temperatures of treatment. When, however, either the prefumigation or more especially the postfumigation temperature was high as well as the actual fumigation temperature the injury was, in general, noticeably more severe than at cooler temperatures. This is well illustrated by a comparison of experiment 1 with either experiment 14 or 15. Unfortunately none of the experiments performed at temperatures exceeding 80° F. were held at a uniform heat throughout the exposure, but the temperature fluctuated at least several degrees after the plants were inclosed in the fumigatorium. This condition introduces a secondary factor which must be taken into consideration in drawing conclusions as to the effect of high temperatures on plant injury.

It appears from a comparative study of the experiments in this paper that severe injury is most noticeable where any two or all three of the fumigation environments, prefumigation, fumigation, and postfumigation, are at high temperatures. In short, if the actual fumigation temperature is high, a minimum of injury is likely to follow if both the other environments are cool. If, however, either the prefumigation or more especially the postfumigation temperature is also high, much more severe injury is likely to result. The evidence

presented in experiments 1 to 27 appears to indicate that the greatest safety demands fumigation at temperatures below 80° F., unless the dosage is weak or the exposure short, and this condition has been corroborated by experiments in orchard treatment.

SUDDEN CHANGES IN TEMPERATURE DURING FUMIGATION.

The following four experiments, when viewed in the light of data given in the preceding experiments, show the effect of a sudden increase in temperature immediately before or during the first few minutes of exposure and followed by a fluctuation of several degrees during the remainder of the treatment. The actual temperature during the gas treatment in the first three experiments was 86° F. or above, while in experiment 27 it was cool, ranging from 61° to 70° F.

EXPERIMENT 24.

Condition during fumigation, dark, 86°–92° F.

Condition before fumigation, dark, 64° F.

Dosage, 1 ounce NaCN.

Date, September 23, 1915, 6.10–6.50 a. m.

Plants in each test, 4; total, 20.

Remarks: Temperature of fumigatorium was raised from 64° to 92° F. immediately before fumigation and held at 86°–92° F. throughout the exposure. Maximum temperature for day, 93° F. at 2 p. m.

Results.

Condition after fumigation.				
Dark, 65° F.	Shade, 67° F.	Dark, 73° F.	Shade, 73° F.	Sun, 73° F.
4	4	4	4	5

EXPERIMENT 25.

Condition during fumigation, shade, 86°–92° F.

Condition before fumigation, dark, 65° F.

Dosage, 1 ounce NaCN.

Date, September 23, 1915, 7.10–7.50 a. m.

Plants in each test, 4; total, 20.

Remarks: Temperature of fumigatorium was raised from 73° to 92° F. immediately before fumigation and held at 86° to 92° F. throughout exposure. Maximum sun temperature for day, 93° F. at 2 p. m.

Results.

Condition after fumigation.				
Dark, 65° F.	Shade, 67° F.	Dark, 75° F.	Shade, 75° F.	Sun, 75° F.
4	4	4	4	5

EXPERIMENT 26.

Condition during fumigation, shade, 86°–91° F.

Dosage, 1½ ounces KCN.

Date, March 18, 1915, 2.05–3.05 p. m.

Plants in each test, 2; total, 20.

Remarks: Temperature of fumigatorium was raised from about 75° to 91° F. immediately before fumigation and maintained at temperature of 86°–91° F. throughout the treatment.

Results.

Condition before fumigation.	Condition after fumigation.				
	Dark, 63° F.	Shade, 65° F.	Dark, 91° F.	Shade, 95° F.	Sun, 74° F.
Dark, 63° F...	4	4	4	4	4
Sun, 77° F...	4	4	4	4	5

EXPERIMENT 27.

Condition during fumigation, shade, 61°–70° F.

Condition before fumigation, shade, 54° F.

Dosage, 1½ ounces KCN.

Date, March 30, 1916, 7.12–8.02 a. m.

Plants in each test, 6; total, 12.

Remarks: Temperature of fumigatorium was raised from 54° to 70° F. during application of gas and was held at a fluctuating temperature of 61°–70° F. during treatment. Rise in temperature was accomplished in 2 to 4 minutes.

Results.

Condition after fumigation.	
Shade, 57° F.	Sun, 61° F.
5	5

RESULTS.

The experimental evidence presented in this paper indicates that for citrus trees the safest temperatures surrounding fumigation fall below 80° F. Yet in experiment 27, in which the temperature at no time departed from this optimum, the plants were almost defoliated. Experiments 3 and 8 were conducted with equally tender plants, with the same dosage, with the same exposure in one case though a little less in the other, and at comparable prefumigation and post-fumigation temperatures, yet the plants in these two experiments had merely the tender growth burned. A detailed comparison of experiments 3 and 27, however, shows a difference in temperature fluctuations during the exposure to gas, it appearing that experiment 3 was performed at a constant temperature of 57° to 58° F., whereas in

experiment 27 the temperature was suddenly raised during the initial exposure to the gas from 54° to 70° F., a rise of 16°, and fluctuated within the range of 61° to 70° F. during the exposure. It would appear that the shock to the plant resulting from this sudden rise in temperature during the gas exposure accounts for the greatly increased injury in experiment 27 over that in experiment 3 or experiment 8.

The effect of a sudden rise of temperature is also shown in experiments 24, 25, and 26, all of which were performed at temperatures ranging from 86° to 92° F., which are much higher than that of experiment 27. An examination of experiment 25, in which the pre-fumigation temperature was 65° F. and in which part of the postfumigation conditions were equally favorable, shows that the injury is very severe irrespective of prefumigation or postfumigation environment, in all cases a large proportion of the most resistant leaves being destroyed. The degree of plant injury was much greater than that in experiments 14 and 18, which were performed at equally high temperatures with the same dosage and exposure. In experiment 25 the temperature was quickly raised 19°, from 73° to 92° F., immediately before generating the gas, and was maintained between 86° and 92° F. throughout the treatment. This sudden rise in temperature, supplemented by fluctuation during the exposure, appears to be the cause of abnormally severe plant injury. The results in experiments 24 and 26 are in full accord with that in experiment 25, and corroborate the influence of a sudden rise of temperature immediately before and during the exposure of plants to hydrocyanic-acid gas.

Experiments 14, 15, and 18 also fall within the class of tests in which the temperature was raised during the exposure of plants to the gas. The injury in these experiments is comparatively less than in Nos. 24 to 27.

An examination of the data presented in this paper shows that all experiments performed at high temperatures (above 85° F.) indicate a greater degree of injury, in general, than where plants are treated at cooler temperatures. In each of these experiments the high temperatures were attained by increasing the heat artificially during the gas exposure. These sudden increases in temperature during the fumigation exposure varied from 10° in experiment 14 to a maximum of 28° in experiment 24. Furthermore, after increase to the maximum temperature, fluctuations took place during the actual gas exposure ranging from 2° in experiment 14 to 10° in experiment 27. This condition of sudden rise in temperature, especially when accompanied by wide fluctuation during the exposure, appears to exert a highly injurious influence on the plant. Where the rise of temperature was only 10° to 14°, as in experiments 14 and 18, and was held during the exposure with slight fluctuations of 2° to 4°, the

injury was not especially severe; where, however, the sudden increase was over a wider range, as in experiments 24 to 27, of from 16° to 28° and accompanied by fluctuation in temperature of 5° to 10°, the injury was most severe.

These data are of importance in showing that sudden and wide fluctuations of temperature during the gas exposure should be avoided where possible. Such fluctuations appear to be damaging to plants even where the ranges of temperatures of exposure fall below 70° F., which is considered within the range of optimum for field fumigation.

GENERAL DISCUSSION OF FACTORS WHICH INFLUENCE FUMIGATION INJURY.

Evidence has been presented in the foregoing experiments bearing on the relation of darkness, diffused light, sunshine, temperature, and moisture to foliage injury during the fumigation of citrus trees. Abundant additional data have accumulated during field and laboratory experiments to offer further corroboration of the deductions made from these experiments. The effect of hydrocyanic acid on fruit was not taken up in connection with this series of laboratory experiments, but a very large amount of data on this subject has been taken during field experimentation.

In the fumigation of citrus trees injury to fruit and injury to foliage should be considered separately. The fruit has been observed to be severely injured without the foliage being burned in the least, while on the other hand trees have been noted as defoliated although the fruit was entirely uninjured. Several different types of injury are presented in the fruit and foliage of fumigated citrus trees. These types, though somewhat related in the case of either the fruit or the foliage, are sufficiently distinct to be easily detected.

Foliage injury is properly characterized by discoloration or burning, and is usually accompanied by the shedding of leaves which vary in appearance from those completely burned to others free from defacement of tissue. The tender expanding leaves of very tender succulent stems usually show the first signs of fumigation injury, and this is not localized at any particular place, but sometimes occurs at the edge and sometimes in the body of the leaf. These affected areas are frequently confined to one surface of the leaf though more commonly the injury is equally apparent on both surfaces. As the degree of injury increases the entire tender tips are affected, this at first being evidenced by wilting and finally by death. The length of time following fumigation before tip injury appears depends upon the tenderness of the tip, the concentration of the gas, and such factors as temperature and sunshine conditions surrounding the fumigation. The tender foliage of plants placed in bright sunshine immediately after treatment with a strong dosage may start wilting or dis-

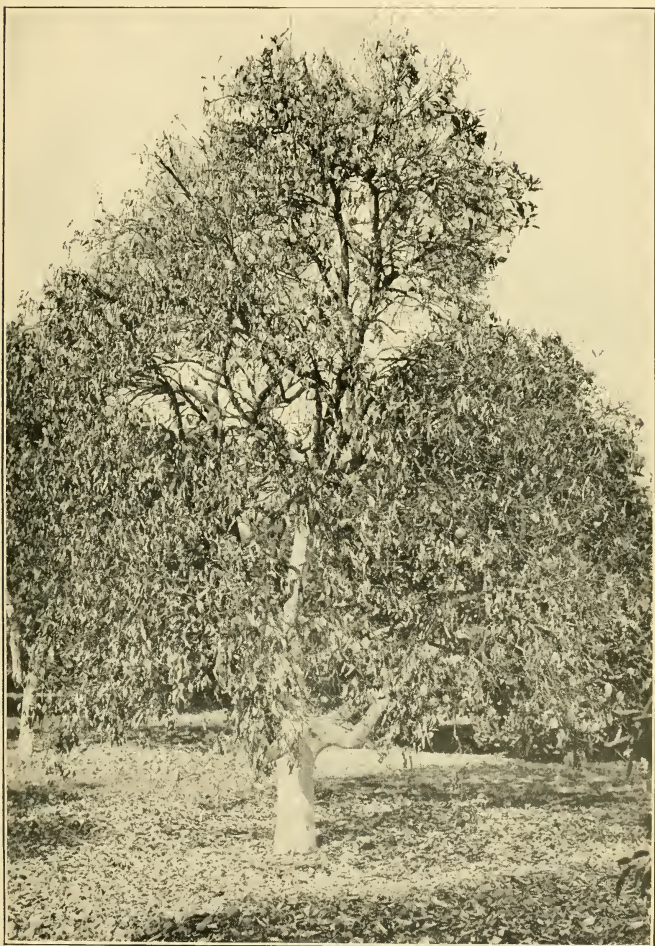
coloration within 2 to 3 hours after the exposure. However, like plants fumigated under like conditions but placed afterwards in the shade or darkness at a cool temperature might not show injury for at least a half day. As a general rule, evidence of injury to active citrus trees unexposed to the direct sunshine for at least several hours after the treatment develops within 24 hours, though the severity of injury may not become fully apparent for 2 or 3 days. Where plants are hardened or dormant at time of fumigation a much longer period is covered before the effects of treatment are definitely exhibited.

Burning of the tender, fully expanded leaves in which the cuticular layer has not yet become fully matured requires a slightly stronger gas than to produce tip injury. As the expanded leaf matures greater resistance to the gas develops. The injury to leaves as observable by defaced tissue may be confined to small distinct areas, sometimes in the case of very tender growth not larger than the head of a pin, or in other cases may include the whole of a leaf. Severely injured leaves drop within a few days to several weeks after treatment, but the shedding of foliage having little or no defacement of tissue is indeterminable because such foliage, especially in the case of mature leaves, might be and apparently is greatly affected physiologically even when little or no superficial evidence is presented previous to the actual abscission. The abscission usually occurs at the base of the blade (Pl. IV, B, *b*) rather than the base of the petiole, but later this also falls.

In any examination into the causes producing plant injury from fumigation with hydrocyanic-acid gas at least four distinct conditions, each of which contributes toward modifying the result, must be considered. These are: (1) The concentration of the gas; (2) the length of exposure; (3) the physiological condition of the plant; (4) atmospheric conditions.

THE CONCENTRATION OF THE GAS.

The modifying influence of gas concentration on plant injury has already been briefly mentioned in this paper. It has been found in experimental work that under the most favorable conditions of treatment fully one-half ounce of high-grade sodium cyanid to 100 cubic feet of space in an air-tight fumigatorium is required to produce injury to normal healthy citrus plants, and dosages in excess of this amount were used in experiments 1 to 27. In orchard work fruit or foliage injury seldom results unless upward of 50 per cent strength of the full dosage schedule recommended by this department and followed in commercial fumigation in California is used. As the gas concentration increases above the strength required to produce initial injury the effect on the plant becomes increasingly severe. In extreme cases the entire plant may be killed, but this result with



FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A Valencia orange tree fumigated six months after the trunk and main branches had been painted with Bordeaux paste. All the foliage was burned and the fruit ultimately dropped.



FUMIGATION OF CITRUS PLANTS WITH HYDROCYANIC ACID.

A, B, Fumigation injury to foliage at point of infestation with purple scale (*Lepidosaphes beckii*). The injury appeared most prominent on the side of the leaf opposite the infestation. *A*, Upper side of leaf, showing purple scale. *B*, Lower side of same leaf, showing collapsed tissue opposite scale infestation. *C*, An immature Valencia orange injured by exposure to sunshine following fumigation. The uninjured area was shaded by leaves. *D*, Twig from a fumigated tree, showing how the leaves are abscised at the base of the blade, leaving the petioles clinging to the tree.

citrus trees is seldom experienced, so extended is the range between initial injury and death.

It has been shown by the author (21) that the distribution of gas beneath the tent is modified by the method of application; that in pot-generated gas the greatest concentration is toward the top of the tree, whereas in the case of gas generated from liquid hydrocyanic acid the concentration is greatest toward the bottom of the tree. Correspondingly the injury in the case of pot or machine generated gas is most marked toward the top of citrus trees fumigated after this method; whereas, when liquid hydrocyanic acid is used, the tendency is for greater injury toward the bottom.

THE LENGTH OF EXPOSURE.

Variations in the length of exposure very naturally modify the effect of the gas on the plant, as early pointed out by Woods and Dorsett (22), and recently clearly presented by Fernald, Tower, and Hooker (5) in experiments with tomatoes and cucumbers. These latter writers performed experiments in which plants were entirely uninjured when exposed to a certain dosage for 10 minutes but when exposed to the same dosage for 2 hours the plants were killed. The writer has performed many similar experiments with citrus trees and reached the conclusion that for these plants very heavy dosages may be safely used with exposure periods up to 20 or 25 minutes' duration, but where the period of exposure approaches or exceeds 40 minutes the injury is decidedly increased.

Whereas short exposures to hydrocyanic acid have very little deleterious effect on plants, a correspondingly less destructive action to insects occurs with short exposures than with long exposures. In the commercial fumigation of citrus trees for scale insects the normal exposure ranges from 40 minutes to 1 hour. Results under shorter exposures with the dosages used have not proved entirely satisfactory from the standpoint of killing the scales. Experiments by the writer have shown that satisfactory results can be secured with shorter exposures if an increased dosage is used. If, however, the exposure with these increased dosages is greatly extended more injury results. Since commercial outfits consist of from 30 to 100 tents, their movements under all conditions within fixed periods of less than 40 minutes is scarcely practicable. At the present time it is not uncommon for large outfits operating on the basis of an hour's exposure to require $1\frac{1}{2}$ hours for shifts or throws with damp tents on large trees. Thus commercial orchard fumigation appears to resolve itself into using dosages which will not injure trees even when the length of exposure slightly exceeds an hour. An outfit consisting of such a few tents that they would be operated unfailingly within short periods could undoubtedly fumigate successfully with greater dosages and shorter exposures than are now common to the practice.

THE PHYSIOLOGICAL CONDITION OF THE PLANT.

The influence of the physiological condition of the plant on injury has until recently received scant attention by writers on fumigation. It is evident that plant injury from hydrocyanic acid is influenced by the chemical condition of the cells at the time of treatment, for otherwise how could the fact, well known to every fumigator, be explained that tender growing citrus plants are less resistant to gas than those in a dormant and hardened condition, as during the winter. This is equally true with the young leaves as with the mature ones, which indicates that in becoming resistant young growth passes some sort of maturation process. In fact it appears that the condition of citrus plants which renders them hardy or resistant to frost injury likewise develops increased resistance to hydrocyanic acid.

Harvey (8) has shown that in the case of cabbage the hardening process results in an increase in the glucose and sucrose content over that present in nonhardened plants and quotes Lidforss as authority for the statement that this is a common transformation in plants generally during the cold season. Chemical changes increasing or reducing the percentage of other substances are also shown to be a result of hardening tissues. It is further stated that the hardening of plants which results in an increase in the cell-sap concentration is an accommodation brought about by low temperature. Plants can also be rendered resistant by growth in a dry soil.

Stone (18), working with cucumber plants grown under different light and soil-moisture conditions, showed that the development of tissue is influenced by these factors as well as their susceptibility to burning with hydrocyanic acid. The weaker tissue produced by inferior light or excessive moisture was decidedly more injured than that grown under full light conditions or in dry soil.

More recently Clayton (1) experimented with tomato plants and similarly observed that resistance to hydrocyanic-acid gas was modified by the conditions under which the plants were grown. Slow-growing plants with a high chlorophyll content per unit area were found to be more resistant to hydrocyanic acid than plants grown rapidly with low chlorophyll content per unit area, and his conclusions that the water supply was the underlying cause of these differences is in full accord with the prior work of Stone. Chemical examination of the two sets of plants gave results in agreement with those of Harvey (8) and others for hardened and nonhardened or actively growing plants, that the more resistant forms have greatly increased carbohydrate content, especially of the reducing sugar calculated as dextrose. Experiments conducted by this writer with plants infiltrated with dextrose showed that resistance to hydrocyanic-acid gas was developed by this procedure and the conclusion was reached that glucose in a plant acts as a protective agent against injury by cyanid.

This important conclusion offers a possible explanation of certain features which the writer has observed in connection with orchard fumigation, namely, the greater resistance of the blossom growth than that of the leaf growth appearing at the same time on the same tree; the greater resistance of this first leaf growth in the winter or spring than that which develops during the hot summer months; the greater resistance of the ripening orange than that of immature fruit.

That chemicals in the cell sap other than reducing sugars can modify injury is strikingly brought out in the case of citrus trees sprayed with Bordeaux mixture or where trunks and main branches have been painted with Bordeaux paste a short time before fumigation with heavy dosages. This damage attributable to Bordeaux applications is evidenced by burning of the foliage and fruit. Plate III shows the severity of injury that frequently follows the fumigation of a tree whose branches and trunk were previously Bordeaux painted. Since the foliage and fruit of this tree were not touched by the Bordeaux paste, but only the branches and trunk, it is evident that certain elements of the fungicide must have been taken into the cell sap and transported to the fruit and foliage which was so severely injured. Proof of this contention has been seen in the extraction of traces of copper from the foliage of such treated trees by Mr. H. D. Young,¹ while chemist of the Citrus Experiment Station at Whittier, Calif. It would thus appear probable that the injury, at least in part, was due to reaction of the cyanid gas on the copper for which it has a great affinity.

It has been observed by the writer (20) that fruit injury from fumigation often occurs at places of weakness in the epidermis and that such a condition is sometimes the result of insect action. Plate IV, A, shows that insects can likewise influence injury to leaves by feeding. In this particular case it is of great interest to note that the injury is most apparent at the leaf surface opposite to that on which the insects rest.

It has been pointed out by different authors that the moisture conditions surrounding growing plants influence their development and their susceptibility to injury from hydrocyanic-acid gas, those growing under moist conditions being less resistant to gas than those growing under dry; in short, that dry soil induces gas-resistant plants. Studies made by the writer in the case of field-grown citrus trees appear in general to support this theory. A large lemon orchard, through which a deep, narrow swale extended, was fumigated in November, 1918. At the time of treatment the soil in this swale was moist and had been in this condition at least since the previous irrigation six weeks before. The soil on the upper slopes was very dry. The tents were pulled in a straight string which extended down the slope on

¹ From unpublished results.

across the swale and up on the other side. The three or four trees of each row which were in the damp soil of the swale were severely injured, whereas the trees in the dry soil of the upper slope were entirely uninjured. In another case a 16-acre orchard on heavy soil had been abundantly irrigated twice during the month prior to fumigation and was very moist at the time of fumigation. This orchard was severely injured throughout, whereas an adjacent orchard of the same soil type which had been without irrigation for so long that the soil was dry and the foliage of a hardened appearance at the time of treatment showed very little injury to any trees. Many similar instances of greater injury on damp soil have been noted.

The mere wetness of the soil does not in itself offer full explanation of plant injury due to this factor. For instance, the writer has conducted fumigation of orchard trees immediately following a heavy rain with no more injury than to trees in dry soil. Likewise fumigation frequently follows immediately after an irrigation without noticeable damage to the trees. The writer's own observation inclines him to believe that the greater injury to citrus trees in wet soil is induced especially after the plants have been subjected to a very moist condition for a sufficiently long period to set in action forces which change the general metabolism of the plant and result in foliage or fruit so constituted as to be less resistant to hydrocyanic acid. Support to this is presented by the work of Fowler and Lipman (6) on the effect of soil moisture on young lemon trees. These writers concluded that soil moisture in excess of the optimum leads to depressed growth, light colored foliage, and general lack of vigor, the visible damage being greater than if the moisture condition is below the optimum. Of further interest is the statement of Pfeffer (15) that the supply of water affects the formation of cuticle. Although a dry soil tends to slacken growth and hasten maturity of plants, thereby rendering them more resistant to hydrocyanic acid, it has been observed that protracted situation in soil so deficient in moisture that the plant suffers ultimately leads to a physiologically weakened condition. It has been stated elsewhere in this paper that plants in a state of impaired health are more susceptible to injury than normal healthy plants.

The soil type also appears so to influence the physiological condition of the tree that modified reaction to hydrocyanic acid sometimes occurs. A 30-acre lemon orchard which was fumigated experimentally in 1918 was about equally divided between two distinct soil types, one a loam designated as a "barren" soil, the other black adobe which contained about 10 per cent humus. Injury occurred throughout this orchard but the degree was noticeably greater on the loam than on the black adobe. Other instances of injury due to different soil types have been noted. Groups of trees

whose growth has not kept pace with the rest of an orchard, due possibly to inferior subsoil, to hardpan, gravel, etc., are not uncommon. Trees under such adverse conditions have sometimes been noted to be more adversely affected by fumigation than healthier trees.

The general conclusion to be drawn from this discussion is that plants best resist cyanid gas if in a hardened or dormant condition at the time of fumigation. Hardening is brought about either by cold weather or a dry soil. From the standpoint of the action of cold, plants are most matured or dormant during the winter season and at this time least injury from fumigation is to be expected. Since citrus is mostly grown in countries that practice irrigation, the dryness of the soil can be regulated by regulating irrigation. Therefore, as a general rule, fumigation should precede the run of water rather than follow, as is frequently the practice at the present time.

ATMOSPHERIC AND LIGHT CONDITIONS.

DARKNESS AND DIFFUSED LIGHT.

Experimental evidence presented in this paper has shown that diffused light before, during, or after fumigation in no way modifies the degree of injury to citrus trees. Since the active stomata of citrus plants open during the daytime and for the most part remain closed at night it is evident that the condition of the stomata does not noticeably alter the degree of injury from fumigation. Such a conclusion is not fully in accord with the statement of Clayton that "the stomata seem to be the most important single factor in determining the amount of injury resulting from hydrocyanic acid * * *. Injury closely paralleled the stomatal movement, increasing as the size of stomatal aperture increased."

These differences in results are readily explained in the light of the work of Stone (18) and Moore (11). The former states that the condition of the stomata does not appear to have anything to do with susceptibility to burning from fumigation but the injury is due rather to the development of the cuticle and texture of the tissue in general; that tender immature tissue is least resistant to fumigation injury. Moore has shown that hydrocyanic acid enters plants to a greater or less extent through the cuticle and that those with thin cuticles are far more severely injured than those with thick, strongly cutinized cuticles. Geranium, Tradescantia, and tomatoes, the plants with which Clayton worked, have very thin cuticles and were injured with a concentration of gas at the rate of approximately $\frac{1}{15}$ ounce of potassium cyanid to 100 cubic feet. The smallest dosage used in the writer's experiments with the thicker and more heavily cutinized citrus plants was 1 ounce of potassium cyanid to 100 cubic feet.

This shows the comparative resistance of the two types of leaves. Mature citrus leaves are so resistant to cyanid that it appears that the concentration needed to produce injury is so great that the gas penetrates the tissues whether the stomata are open or closed, and the amount which enters while the stomata are open over that entering while closed¹ is insufficient to modify to any great extent the degree of injury. Of particular interest in this connection are the observations of Coit and Hodgson (2) that early in the life of the leaf the stomata lose their power of opening and closing and remain for the most part practically closed thereafter. On the other hand, such tender plants as *Tradescantia* react to such small amounts of cyanid that the stomata seem able to exercise an influence on the passage of gas sufficient to modify the effect on the plant.

SUNSHINE.

The earliest fumigation of citrus trees was performed during the daytime and accompanied by much injury. Coquillett (3) offered as an explanation of this result that "in the daytime the light and heat decompose the gas," the assumption being that the products of decomposition are more injurious than the hydrocyanic acid gas itself. In an effort to correct the action of sunlight blackened tents were used but without marked success. The final solution was night fumigation. American writers on fumigation who have experimented with sunshine work have been unanimous in proclaiming its impracticability as a general practice.

The results of the many experiments presented in this paper show that sunshine is one of the most important factors influencing injury and that its effects are not confined solely to the period of exposure, but are also exerted immediately before and immediately after the treatment. The postfumigation influence appears to be somewhat greater than the prefumigation influence and its effects are sometimes so injurious as to discolor fruit (Pl. IV, B, *a*) and destroy the foliage of plants which, if protected from the direct sun, would have been but slightly affected (Pl. I, B). This action on the foliage is most conspicuous through burning which, if including the entire petiole as well as the blade, results in the destroyed foliage clinging to the tree until exfoliation takes place by mechanical means. (Pl. II, B.) This postfumigation sunshine influence in such experiments as No. 10, in which plants in the dark were fumigated in the dark and placed in the sunshine with the result of severe injury, would appear to disprove Coquillett's explanation of decomposition of the gas, for in this case the sunshine did not reach the plants until they had been removed from the fumigatorium.

¹ According to MacDougal (19) stomata do not close their pores so tightly that some gaseous diffusion may not take place through their diminished opening.

Temperature has a very direct relation to sunshine influence, and the degree of injury appears to be increased or decreased as the temperature of the sunshine is greater or less. Furthermore, where plants are subjected to sunshine immediately before treatment, the actual fumigation and postfumigation temperatures influence the degree of injury. Likewise in the case of plants exposed to sunshine immediately after treatment, the prefumigation and actual fumigation temperatures require consideration. The writer's own experimental evidence shows that the optimum temperatures of fumigation are below 80° F., and that work conducted at higher temperatures is performed with increased risk. The greatest injury follows the subjection of plants to both sunshine and high temperatures both before and after fumigation. The effect of this combination, sunshine and temperature, has long influenced the time of starting orchard work in California. The fumigation season begins in the summer and extends throughout the autumn into the winter. During the warmest weather work is not started until the sun has set, but with the advent of the late autumn and cooler temperatures the first row of trees is sometimes covered before sundown, and in the winter period of dormancy entire rows are treated in the sunlight. During very hot weather, when the atmosphere is clear and dry, injury to the first row fumigated at night and the last in the morning has been of frequent occurrence and in the latter case has been observed to occur even when the tents were removed from the trees before sunrise. Full explanation of this situation is presented in the results of experiments 20 to 23 which show that the postfumigation sunshine influence may extend up to three hours after exposure, although the maximum of influence is confined to the first few minutes after removal from the gas.

In spite of the fact that sunshine has from the first been considered one of the most harmful agents to plants in connection with fumigation, the greater desirability of daylight work has led to continued attempts to substitute day practice for that at night. These efforts to revolutionize accustomed practice usually were made during the winter months, and frequently successfully over short periods if the weather was moderate and the trees well hardened. Sooner or later, however, this attempt to fumigate by day without modification of dosage or exposure was followed by severe tree damage and was promptly discontinued.

It has been explained previously that cyanid injury is modified by the concentration of the gas and by the length of exposure. Therefore it is reasonable to assume that either of these factors can be so reduced as to render fumigation safe on the hottest sunny day. Orchard work is performed with a concentrated gas, usually as concentrated as an active tree will stand safely during cool nights. In

the light of the experiments presented in this paper it is to be expected that the use of such dosages during warm sunshine would cause severe injury. Experiment 3 shows that by reducing the strength of the gas the influence of the sunshine is correspondingly reduced. One orchardist known to the writer has practiced daylight fumigation on his small lemon orchard during the growing season for several years, accomplishing his purpose through reduction of both dosage and exposure. He was observed on one occasion to fumigate lemon trees safely at a temperature of 84° to 86° F. by using a dosage calculated as less than one-half the usual dosage, with an exposure of 30 minutes. The effect on the scale was not noted.

Since liquid hydrocyanic acid has come to be used in fumigation, daylight practice is no longer considered a dangerous experiment. During the winter months outfits operate throughout the daytime in bright sunshine, in many cases with complete safety, and under conditions which in the past with pot or machine generated gas were wont to produce severe injury. Outside of possible differences in physical properties of the gas due to the method of generation and application, the one most plausible reason for the increased safety of daylight operation is the difference in diffusion throughout the tree. In pot-generated gas the greatest concentration is toward the tree top, whereas with liquid hydrocyanic acid in warm weather the greatest concentration is toward the bottom of the tree (21). The writer has determined by a series of experiments that the temperature of the tented tree rapidly rises on the sunward side after covering and that the greatest increase is toward the top of the tent. In pot-generated gas the maximum gas concentration, maximum heat, and most sudden change of temperature are exerted at the same place, the top of the tree, whereas in trees fumigated with liquid hydrocyanic acid the greatest concentration of gas at the bottom of the tree is at the coolest part of the sunward side of the tree, while at the top or point of maximum temperature the gas is most dilute. A seeming explanation is presented in the comparative appearance of damaged trees under these two methods of gas application. Sunshine-injured trees from pot-generated gas show the greatest damage on the sunward side toward the top; in the case of trees treated with liquid hydrocyanic acid the damage toward the bottom is greatly increased over that as compared with pot-fumigated trees while that toward the top is lessened.

It was stated in a previous paragraph that the open or closed condition of the stomata does not appear to affect the degree of injury to citrus plants in darkness or diffused light before, during, and after fumigation. In the case of plants subjected to sunshine either immediately before or immediately after exposure to cyanid gas, equally conclusive data bearing on this subject have not been developed. Cer-

tain experiments already presented in this paper have shown that plants in a prefumigation and fumigation environment of darkness (indicating closed stomata) were severely injured by placement in sunshine immediately after the exposure, while check plants placed in the shade at an equal temperature were little affected. In these cases the increased damage to the sun-exposed plant was brought about in spite of the fact that the stomata were apparently closed during the fumigation. Furthermore, data have been collected during daylight work, both in the morning and afternoon, showing that trees somewhat protected from the direct sun were little affected by a strength of gas that severely injured trees in the direct sunshine treated at the same time. On the other hand, the increased injury to plants in a prefumigation condition of sunshine, as previously explained, and observation that greater injury is usually apparent during morning orchard fumigation than during that performed late in the afternoon at an equal temperature, might indicate possible stomatal influence when viewed in the light of Lloyd's (9) conclusions that the morning sun may hasten stomatal opening, that this opening is at its maximum toward midday, and that closure occurs during the afternoon.

Stone, Moore, and others conclude that a strong concentration of gas tends to close the stomata. This closure of the stomata from fumigation would reduce the rapidity of the escape of gas which remained in the intercellular spaces after treatment and might thereby modify the degree of injury, especially in plants subjected to such adverse conditions as postfumigation sunshine.

The condition of the soil apparently influences cyanid injury from sunshine, as shown in the case of a 10-acre citrus orchard fumigated during a clear hot day in November, 1919. This orchard was so irrigated that the soil nearest the head of the furrows was thoroughly wet to a normal depth, whereas the soil at the lower end of the furrows was for the most part wet only for a few inches at the surface, or sometimes not at all. The trees reflected this lack of required moisture in their general less healthy appearance. The tents were strung in the direction of the irrigation furrows. Severe injury resulted from the fumigation, amounting almost to complete defoliation on the sunward side of a large part of the trees. This injury was confined almost exclusively to the trees on the dry soil, those on the moist soil being very little affected. The explanation is that the trees which had long suffered from lack of moisture were in a weakened condition at the time of fumigation, whereas the others were not.

TEMPERATURE.

It has been clearly shown by the experimental evidence presented in this paper that temperature exerts one of the most important modifying influences on injury from fumigation. Furthermore, not

only must the temperature of treatment be considered, but also the temperature surrounding plants after exposure and to a much less extent that before exposure. It has been shown that high temperatures are more injurious than low, and in the case of each of the three fumigation environments, the prefumigation, actual fumigation, and postfumigation, the maximum optimum fell below 80° F. Exactly how much this maximum for any particular environment fell below 80° F. depended on the temperature of the other two; when any two were low the maximum optimum for the third approximated 80°; when they were high, however, the maximum for the third was a few degrees less than 80°. In one case it did not exceed 75°. These conclusions differ very little from the writer's experience in orchard fumigation in southern California, for which 70° is held as the maximum when a heavy dosage is used. This same maximum is recommended by Sasscer and Borden (16) for greenhouse plants. An interesting relation apparently exists between the maximum optimum temperature for fumigation and the activity of plants, for MacDougal (10) states that temperature is one of the most widely interlocking factors concerned in the activity of protoplasm, and that the temperature of greatest activity in seed plants varies from 80° to 100° F. The experimental work presented in this paper shows increasing fumigation injury as the temperature of 80° is approached or exceeded, which corresponds with the degree at which greatest protoplasmic activity commences.

It is possible to conduct fumigation at temperatures of 80° F. or above without serious injury provided the prefumigation and postfumigation conditions are ideal. A high postfumigation temperature increases the probability of damage, and especially is this true if the fumigation temperature is also above the optimum. The greatest damage follows when all three temperatures surrounding the treatment are high. A prefumigation temperature in shade and darkness, even up to 100° F., appears to alter the results very little unless the fumigation or postfumigation temperature is also high, in which case the high prefumigation temperatures are more injurious than the low. The temperature of 55° F. was the minimum at which experimental work was conducted. The little injury evidenced at this temperature showed it to be within the range of the optimum. In field work it has been stated by the writer (19) that operations are safe as low as 38° F., although fumigation below this point is not advocated.

In experiments 24 to 27 it was shown that a sudden increase in temperature immediately preceding or during the first few minutes of exposure produces very severe injury, especially if followed by sharp fluctuations of temperature. This factor offers a partial explanation for the severe injury in sunshine fumigation on the sunward side of the tree, especially toward the top, and also presents a

reason for the less amount of injury in daylight fumigation with liquid hydrocyanic acid. This is shown by Table III, in which are presented data giving the increase in temperature at different parts of a 12-foot tree covered with a canvas tent, December 17, 1919.

TABLE III.—*Rise in temperature at different points within a tented citrus tree in the sunshine at varying periods following the covering. Thermometers placed from 6 to 10 inches from the canvas.*

Minutes after start.	Rise in temperature. ^a		
	Sunward side, 11 feet altitude.	Sunward side, 4 feet altitude.	Shade side, 4 feet altitude.
5	8	3	2
10	16	9	3
15	22	12	5
20	26	12	6

^a Sun temperature at start, 75° F.; shade temperature, 69° F. Time, 10.43 a. m.

It is shown in this table that an increase of 26° occurred toward the top of the tent on the sunward side within 20 minutes after covering, whereas at the same time on the same side 4 feet from the ground the increase was only 12° and on the shaded side of the tree at the same height only 6°. Injury in daylight work has been observed to be proportionately greater at these different points in the case of pot-generated gas. The lower part of the shaded side of the tree, at which the temperature increase is very slight, is seldom injured even when very severe burning takes place on the sunward side of the tree.

The effect of the temperature is least felt in the case of thoroughly hardened trees. In fact, the extent to which sunshine fumigation can be practiced during the winter period is attributable largely to the extent of this hardened or dormant condition of the trees. This condition also offers an explanation for the safety of fumigation at very low temperatures, sometimes at the freezing point, whereas at other times, especially in the early fall, while trees are active, severe injury takes place at several degrees above the freezing point. In the Tulare County citrus belt of California the writer has noted night fumigation, with heavy dosages, carried on during the summer at temperatures as high as 85° F. without apparent injury to the plants. Fumigation in the coast region of southern California at such high temperatures would produce severe injury. He believes that this greater safety in the northern citrus region is due largely to the more resistant condition of the plants brought about by the very hot, arid climate during the summer. Duggar (4) states that green leaves exposed to sunlight show a temperature from 2° or 3° to 15° higher than the air, and according to MacDougal (10) the maximum temperature of higher plants varies from 100° to 115° F. At or above the maximum

protoplasm passes into a state of immobility. Since the maximum daily temperature of the Tulare citrus belt during the summer frequently exceeds 100° F., the mean maximum for the hottest months seldom falling more than 1° to 3° below this temperature, a reason for reduced activity is presented.² This condition is doubtless promoted by the usual practice of withholding irrigation until after fumigation. In the more equable, damper climate of the coastal region, where the temperature very seldom attains a maximum of 100° F., but rather approaches the optimum for protoplasmic activity, dormancy during the summer is less noticeable and the physiologically active plants are more subject to fumigation injury.

MOISTURE.

Moisture, even when present in excessive amounts, appears to have no influence on injury to citrus trees either before, during, or after the treatment, under conditions of shade or darkness, and this conclusion agrees with the work of Gossard (7), Morrill (13), and others. Under conditions of exposure to hot sunshine before fumigation the application of cool water appears to reduce the degree of injury slightly. These results on the relation of moisture to the fumigation of citrus trees do not necessarily apply to tender greenhouse plants, for moisture on such plants with thin cuticles has been shown by various authors (11, 18) to produce increased injury. Clayton (1), however, in a recent paper states that some species are made more susceptible to injury by wetting the leaves while other species are not visibly affected. He places the tomato in the latter class although Moore found that wetting tomatoes as well as various other plants with thin cuticle increased their susceptibility to injury.

The influence of soil moisture has been referred to in previous discussions and may be passed with the statement that soil moisture in sufficient quantity to make plants physiologically very active and tender renders plants more susceptible to fumigation injury than where present only in such quantities as place the plants in a resistant or hardened condition.

Hydrocyanic-acid gas has a great affinity for water, and under conditions of excessive moisture sufficient gas might be absorbed to so materially reduce the concentration that less injury would be produced than otherwise, and, furthermore, its insecticidal value would be lessened. Where fumigation is conducted in gas-tight containers this condition can not be ignored, and the necessity of attention thereto has been clearly shown by Penny (14), and Sasscer and Borden (16). In orchard work under cloth tents the absorption of gas by moisture is offset by the greater gas-holding properties of the moist canvas.

² Taken from published records of the U. S. Weather Bureau, which are lower than orchard sunshine temperatures.

SUMMARY.

(1) It is necessary to consider the prefumigation and postfumigation environments of fumigated plants as well as that during the actual treatment.

(2) Sunshine is the chief prefumigation factor that increases injury and this influence is greater at high temperatures than at low. Under darkness or diffused light, temperatures upward to at least 100° F. do not appear to increase injury unless the fumigation or postfumigation temperatures exceed 80° F.

(3) The environment after fumigation approximates in importance that during the actual treatment. Of the postfumigation factors both sunshine and temperature modify the degree of injury. Sunshine, the more important, is most destructive to plants exposed immediately after fumigation, but affects them deleteriously at least two hours after the treatment. Temperatures of 80° F. or above injure plants more severely than lower temperatures.

(4) The fumigation of citrus plants is most safely performed at temperatures below 80° F.

(5) Diffused light before, during, or after fumigation exerts no more deleterious influence than darkness.

(6) Moisture on citrus plants does not increase the degree of injury. An application of cool water to plants in hot sunshine immediately prior to fumigation appears to reduce slightly the effect of the gas.

(7) Sudden changes of temperature over a wide range during exposure to hydrocyanic-acid gas tend greatly to increase plant injury.

(8) The optimum environment for safety to plants is diffused light or darkness at uniform temperatures below 80° F. before, during, and after the fumigation. The lowest temperature tried, 55° F., was within the range of the optimum.

(9) Fumigation at temperatures upward of 80° F. is safest under cool prefumigation and postfumigation environments. The maximum of injury follows high temperatures for all three environments.

(10) The physical and chemical conditions of the soil influence injury from fumigation. Trees in a wet soil tend to be more severely injured than healthy trees in a dry soil. However, trees in soils deficient in moisture for such protracted periods as to be severely weakened are more susceptible to injury than if grown under optimum moisture conditions. Irrigation should follow fumigation, not precede it.

(11) The physiological condition of plants is one of the most important factors regulating fumigation damage. A condition akin to hardiness appears to be the optimum for gas resistance and is brought about by dryness of the soil, cold weather, and possibly by continued very hot dry weather which exceeds the optimum for the plant.

(12) Sunshine fumigation can be conducted with safety by proper regulation of the dosage and length of exposure.

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L. O. HOWARD, Chief

Washington, D. C.

PROFESSIONAL PAPER

December 13, 1920

LIFE HISTORY OF THE GRAPE-BERRY
MOTH IN NORTHERN OHIO

By

H. G. INGERSON

Scientific Assistant, Deciduous Fruit Insect Investigations

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METHOD OF CONDUCTING REARING WORK.

The studies reported in this paper on the grape-berry moth (*Polychrosis viteana* Clem.) began in 1916 with the collection of grapes which were infested with early hatching first-brood larvæ. These infested grapes were taken to the open-air insectary and placed in cylindrical wire baskets which held from 1 to 1½ quarts each. These baskets were placed in glass battery jars which had been supplied with about one-half inch of sand in the bottom. This sand absorbed the juice from the infested grapes and maintained a fairly constant humidity in the jars. The jars were closed with cloth covers.

Fresh grape leaves were placed in the battery jars in the space between the wire baskets and the glass surface, and the larvæ pupated

¹ The data reported in this paper were accumulated during the seasons of 1916, 1917, and 1918. The actual rearing records were secured at Sandusky, Ohio, and the field observations were made in the grape sections about Sandusky, including the Lake Erie islands, in Dover and Avon sections west of Cleveland, and in the Euclid section east of Cleveland.

Control experiments based on these life-history studies were conducted each season and the satisfactory control effected proved the value of such life-history data. The results of the control experiments are published separately as U. S. Department of Agriculture Bulletin 837.

These investigations were conducted in cooperation with the Ohio Agricultural Experiment Station.

During the season of 1916 the writer was assisted by E. R. Selkregg, then field assistant in the U. S. Bureau of Entomology. Mr. Selkregg was in direct charge of the rearing work for 1916. In the seasons of 1917 and 1918 the writer was assisted by Chester I. Bliss, field assistant in the U. S. Bureau of Entomology.

in these leaves. The leaves bearing cocoons were removed each day and fresh ones supplied. The cocoons were placed in small jelly glasses until the moths emerged. The moths were removed each day as the records were taken. To secure oviposition records when the moths are confined several different methods have been tried but all without satisfactory results.

Throughout this work the rearing records have been checked and supplemented by extensive field observations and, except where noted, represent as nearly the actual conditions as it was possible to approximate. Each table presented is to be considered complete in itself and not dependent on any other table. Special methods for the securing of any particular records are given with the records.

WEATHER CONDITIONS IN 1916, 1917, AND 1918.

Seasonal-history data sufficient for accurate timing of spray applications were secured in 1916 and the other data secured were incidental. The weather conditions in the season of 1916 were about normal except for an unusually warm dry autumn. In 1917 the records are more complete, but represent an abnormally late and wet season throughout. The fall was unusually cold and rainy and considerably retarded the development of the second-brood larvæ. In 1918 berry-moth infestation was generally light throughout northern Ohio and difficulty was experienced early in the season in securing sufficient material for rearing records. The season of 1918 opened unseasonably early and remained advanced throughout.

SEASONAL-HISTORY STUDIES, 1916.

These studies began with the collection of early hatching first-brood larvæ in the vineyards. Vineyards known to have been heavily infested in 1915 were searched carefully on June 1, 5, 10, and 14, but not until June 20 was a larva found. At this time only an occasional larva could be found and there was no general infestation of the grape cluster buds. Not until July 5 were larvæ present in the vineyards in any considerable number. Collections of larvæ were made frequently and regularly throughout the season, beginning June 20.

FIRST GENERATION.

TIME OF FIRST-BROOD LARVÆ LEAVING THE FRUIT.

Actual records began with the early hatching larvæ leaving the fruit. Table I shows the dates on which the first-brood larvæ spun their cocoons. The earliest date is seen to be June 28 and the latest August 18, with the greatest number cocooning on July 21. It seems worthy of note that a very large percentage, 81.35 per cent, cocooned within the 12-day period from July 16 to July 27, inclusive.

TABLE I.—*Time of leaving grapes of first-brood larvæ of the grape-berry moth in 1916. Fruit collected at Venice, Put-in-Bay, and Kelley's Island, Ohio.*

Date of leaving fruit.	Number of larvæ.	Date of leaving fruit.	Number of larvæ.
June 28.....	1	July 26.....	142
29.....	1	27.....	139
July 2.....	1	28.....	95
4.....	3	29.....	8
5.....	1	30.....	28
6.....	3	31.....	35
7.....	5	Aug. 1.....	27
8.....	6	3.....	8
9.....	4	5.....	10
10.....	4	6.....	73
12.....	22	7.....	70
13.....	63	8.....	60
14.....	28	9.....	59
15.....	32	10.....	18
16.....	163	11.....	12
17.....	349	12.....	11
18.....	151	13.....	29
19.....	316	14.....	22
20.....	376	15.....	12
21.....	425	16.....	4
22.....	346	17.....	6
23.....	398	18.....	14
24.....	381		
25.....	164	Total.....	4,125

LENGTH OF TIME OF FIRST-BROOD INDIVIDUALS IN THE COCOON.

The time of cocooning and length of time in the cocoon for 38 individuals observed are shown in Table II. The maximum time is 19 days, the minimum 9 days, and the average 11.7 days.

TABLE II.—*Time of cocooning and the length of time in cocoon of the first brood of the grape-berry moth at Sandusky, Ohio, in 1916.*

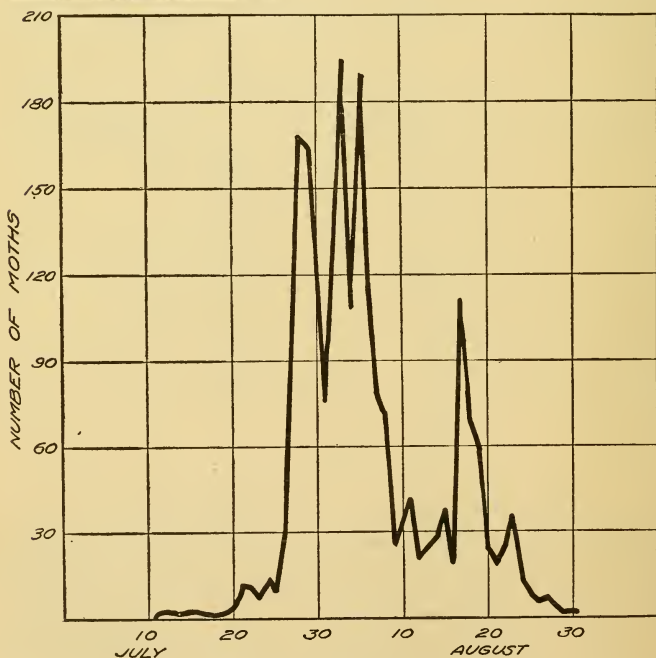
Number of larvæ.	Larvæ left fruit.	Moths emerged.	Days in cocoon.	Total.	Larvæ collected at—
1.....	June 28..	July 11..	13	13	Put-in-Bay, Ohio.
1.....	..do....	July 12..	13	13	Do.
1.....	July 2....	..do....	10	10	Venice, Ohio.
1.....	July 4....	July 14..	10	10	Do.
2.....	..do....	July 15..	11	22	Do.
1.....	July 5....	July 16..	15	15	Do.
1.....	July 6....	..do....	10	10	Kelley's Island, Ohio.
1.....	..do....	July 18..	13	13	Do.
1.....	..do....	July 25..	19	19	Do.
1.....	July 7....	July 17..	10	10	Do.
1.....	..do....	July 19..	12	12	Venice, Ohio.
1.....	..do....	..do....	12	12	Kelley's Island, Ohio.
6.....	..do....	July 21..	14	84	Do.
5.....	July 12..	..do....	9	45	Do.
1.....	July 13..	July 24..	11	11	Do.
10.....	..do....	..do....	11	110	Venice, Ohio.
2.....	..do....	July 25..	12	24	Do.
1.....	..do....	July 26..	13	13	Do.
38		Average.	11.7		
		Ma x i - mum..	19		
		M i n i - mum..	9		

TIME OF EMERGENCE OF FIRST-BROOD MOTHS.

The material for securing emergence records of first-brood moths included the larvæ collected beginning June 20 and shown in Tables I and II, and pupæ collected in the field at frequent intervals. It will be seen in Table III and figure 1 that moths began to emerge July 11 and continued until August 31, with the greatest number on August 3. A large part, 63 per cent, of this emergence came within the 11-day period, July 27 to August 6.

TABLE III.—Time of emergence of moths of the first brood of the grape-berry moth at Sandusky, Ohio, in 1916.

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
July 11.....	1	Aug. 7.....	78
12.....	2	8.....	70
13.....	1	9.....	25
14.....	1	10.....	37
15.....	2	11.....	42
16.....	2	12.....	20
17.....	1	13.....	25
18.....	1	14.....	28
19.....	1	15.....	37
20.....	3	16.....	18
21.....	11	17.....	111
22.....	10	18.....	67
23.....	7	19.....	56
24.....	13	20.....	22
25.....	10	21.....	18
26.....	43	22.....	24
27.....	116	23.....	35
28.....	168	24.....	13
29.....	164	25.....	7
30.....	119	26.....	5
31.....	111	27.....	6
Aug. 1.....	78	28.....	4
2.....	118	29.....	1
3.....	194	30.....	2
4.....	109	31.....	1
5.....	190		
6.....	112	Total.....	2,340

FIG. 1.—Diagram showing time of emergence of first-brood moths of the grape-berry moth (*Polychrosis viteana*) at Sandusky, Ohio, 1916.

OVIPOSITION OF FIRST-BROOD MOTHS.

The oviposition records were secured from some of the moths recorded in Table III. The oviposition of a few of these moths is shown in Table IV. No attempt was made to secure oviposition records throughout the entire oviposition period. From observations made in the vineyards during the season it was found that the heaviest oviposition was in the period from about August 1 to 10. Freshly deposited eggs were found in small numbers in the vineyards as late as August 17, and eggs were being deposited in the insectary as late as September 1.

TABLE IV.—*Oviposition by first-brood moths of the grape-berry moth in rearing jars at Sandusky, Ohio, in 1916.*

No. of jar.	Number of moths.		Date of—			Days—		
	♂	♀	Emergence.	First oviposition.	Last oviposition.	Before oviposition.	Of oviposition.	From emergence to last oviposition.
1.....	2	9	July 24....	July 26....	July 26....	2	1	2
2.....	14	9	July 27....	July 30....	July 30....	3	1	3
3.....	12	18	July 28....	Aug. 3....	Aug. 5....	6	2	8
4.....	(1)	(1)	Aug. 5-6..	Aug. 7-8..	Aug. 11....	2-2	3	6
5.....	3	14	Aug. 22-23.	Aug. 26....	Aug. 26....	4	1	4
Average.....						3.4	1.6	4.6
Maximum.....						6	3	8
Minimum.....						2	1	2

¹ No record.

SECOND GENERATION.

TABLE V.—*Incubation period of second-brood eggs of the grape-berry moth at Sandusky, Ohio, 1916.*

Number of observation.	Date of oviposition.	Date of hatching.	Days of incubation.	Number of eggs.
1.....	Aug. 3.....	Aug. 8....	5	No record.
2.....	Aug. 7-8....	Aug. 11....	4	Do.
3.....	Aug. 9-10...	Aug. 13....	4	52.
4.....	Aug. 11....	Aug. 16....	5	39.
5.....	Aug. 27-28..	Sept. 3....	7	No record.
6.....	Aug. 30....	Sept. 5....	6	Do.
7.....	Sept. 1.....	Sept. 6....	5	Do.

Average length of incubation period, 5.1 days.
Maximum length of incubation period, 7 days.
Minimum length of incubation period, 4 days.

The incubation period of second-brood eggs as shown in Table V averaged 5.1 days with 7 days as the maximum time and 4 days as the minimum. It may be assumed then that the earliest second-brood larvæ began feeding about July 21, 10 days after the emergence of moths on July 11. The hatching, however, was light until about August 5, when larvæ began to be present in the vineyards in large numbers. Though some larvæ hatched in the insectary as late as September 6, in the vineyards most of the larvæ had hatched by August 25.

FEEDING PERIOD OF SECOND-BROOD LARVÆ IN REARING CAGES.

Records from the date of hatching to the date of cocooning were secured from 51 individuals as shown in Table VI.

TABLE VI.—*Feeding period of second-brood larvæ of the grape-berry moth in rearing cages, Sandusky, Ohio, 1916.*

Date of hatching.	Date of cocooning.	Number of cocoons.	Feeding period.	Total.
			<i>Days.</i>	<i>Days.</i>
Aug. 11.....	Aug. 31	2	20	40
Do.....	Sept. 1	5	21	105
Do.....	Sept. 6	4	26	104
Do.....	Sept. 7	1	27	27
Aug. 13.....	Aug. 31	1	18	18
Do.....	Sept. 1	2	21	42
Do.....	Sept. 2	1	22	22
Do.....	Sept. 4	4	24	96
Do.....	Sept. 7	4	27	108
Do.....	Sept. 9	2	29	58
Do.....	Sept. 10	1	30	30
Aug. 16.....	Sept. 1	3	16	48
Do.....	Sept. 4	5	19	95
Do.....	Sept. 9	3	24	72
Do.....	Sept. 10	3	25	75
Do.....	Sept. 11	3	26	78
Do.....	Sept. 12	3	27	81
Do.....	Sept. 14	1	29	29
Sept. 5.....	Oct. 11	1	36	36
Sept. 6.....	Oct. 9	1	33	33
Do.....	Oct. 12	1	36	36
Total.....		51		1,233
Average.....			24.18	
Maximum.....			36	
Minimum.....			16	

The average length of the feeding period for the 51 larvæ was 24.18 days, a much shorter period than has previously been recorded as the average for the second brood. This shortening was due no doubt to the unseasonably warm weather that prevailed during August, September, and early October of 1916. This figure should not be taken as representing the usual condition, but is presented here to show the influence of a warm fall on the maturing of the larvæ. The maximum length of the feeding period was 36 days and the minimum 16.

LENGTH OF THE PREPUPAL PERIOD.

The length of time between the spinning of the cocoon and pupation was recorded for 13 individuals as shown in Table VII.

TABLE VII.—*Length of the prepupal period of 13 individuals of the second brood of the grape-berry moth, Sandusky, Ohio, 1916.*

Date of spinning cocoon.	Number of cocoons.	Date of pupation.	Number of days in prepupal stage.	Total number of days.
Aug. 31.....	1	Sept. 3	3	3
Do.....	1	Sept. 4	4	4
Do.....	1	...do....	4	4
Sept. 1.....	2	...do....	3	6
Do.....	5	Sept. 5	4	20
Do.....	2	Sept. 6	5	10
Do.....	1	Sept. 8	7	7
Total.....	13			54

Average length of prepupal period, 4.15 days.
Maximum length of prepupal period, 7 days.
Minimum length of prepupal period, 3 days.

The average length of the prepupal period was 4.15 days, the maximum 7 days, and the minimum 3 days.

TIME OF COCOONING OF THE SECOND-BROOD LARVÆ.

In an effort to determine the percentage of worms normally removed from the vineyards with the harvested grape crop the following records were secured:

TABLE VIII.—*Time of cocooning of the second brood of the grape-berry moth at Sandusky, Ohio, in 1916.*

Date of cocooning.	Number of co-coons.	Date of cocooning.	Number of co-coons.
Aug. 22	1	Sept. 27	244
Aug. 23	1	Sept. 28	109
Aug. 24	6	Sept. 29	46
Aug. 25	3	Sept. 30	18
Aug. 28	44	Oct. 1	33
Aug. 29	5	Oct. 2	40
Aug. 30	39	Oct. 3	64
Aug. 31	43	Oct. 4	87
Sept. 1	157	Oct. 5	119
Sept. 2	121	Oct. 6	64
Sept. 4	350	Oct. 7	51
Sept. 5	163	Oct. 8	55
Sept. 6	120	Oct. 9	16
Sept. 7	335	Oct. 10	10
Sept. 8	340	Oct. 11	15
Sept. 9	254	Oct. 12	9
Sept. 10	153	Oct. 13	15
Sept. 11	343	Oct. 14	14
Sept. 12	309	Oct. 15	9
Sept. 13	402	Oct. 17	16
Sept. 14	233	Oct. 19	8
Sept. 15	197	Oct. 21	6
Sept. 16	94	Oct. 23	5
Sept. 17	145	Oct. 25	4
Sept. 18	114	Oct. 27	6
Sept. 19	101	Oct. 29	6
Sept. 20	142	Nov. 1	6
Sept. 21	251	Nov. 3	2
Sept. 22	171	Nov. 5	4
Sept. 23	94	Nov. 7	4
Sept. 24	68		
Sept. 25	126	Total	6, 138
Sept. 26	128		

Larvæ began to leave the grapes as early as August 22 and continued to leave as late as November 7. The table further shows that 77 per cent of the larvæ left the fruit previous to September 25, the date of the beginning of the Concord harvest, and that 90 per cent had left the grapes previous to the beginning of the Catawba harvest on October 3. From these data it would seem that little control is effected by the removal of the worms with the crop.

SEASONAL-HISTORY STUDIES, 1917.

The 1917 rearing records begin with the emergence of spring-brood moths from overwintered pupæ. These pupæ were kept under a leaf blanket in the insectary yard, a condition similar to that in a protected part of the vineyard. At the time when "plowing away" from the vines began in the Sandusky section May 14, the cocoons were moved from the wintering place to the insectary, placed in rearing jars, and records of moth emergence taken as shown in Table IX.

TABLE IX.—*Time of emergence and sex of moths of the spring brood of the grape-berry moth, Sandusky, Ohio, 1917.*

Date of emergence.	Number of moths.				Mean daily temperature.	Date of emergence.	Number of moths.				Mean daily temperature.
	♂	♀	¹ ♀	Total.			♂	♀	¹ ♀	Total.	
June 9.....		2		2	62	July 10.....	5	35		40	65
June 10.....		1		1	62	July 11.....	2	6		8	63
June 12.....	2	1		3	70	July 12.....	10	37		47	66
June 13.....	2	1		3	72	July 13.....	1	6		7	64
June 15.....		1		1	51	July 14.....	4	20		24	70
June 16.....	1	1		2	54	July 15.....	8	22	1	31	72
June 17.....		3		3	60	July 16.....	7	20	1	28	74
June 18.....	5	9	3	17	69	July 17.....	5	27		32	72
June 19.....	10	16	2	28	73	July 18.....	1	12		13	70
June 20.....	1	1		2	66	July 19.....	4	28	2	34	71
June 21.....	10	6	3	19	68	July 20.....	3	4	3	10	76
June 22.....	34	46	1	81	68	July 21.....	5	14	2	21	76
June 23.....	3	6		9	72	July 22.....	2	11		13	76
June 24.....	13	51		64	62	July 23.....	1	7		8	78
June 25.....	18	82	2	102	63	July 24.....	1	8		9	80
June 26.....	17	56	3	76	78	July 25.....		7	1	8	78
June 27.....	7	31		38	69	July 26.....		2	1	3	80
June 28.....	32	90	2	124	70	July 27.....		1		1	76
June 29.....	13	39	1	53	68	July 28.....		9	1	10	72
June 30.....	17	79	2	98	69	July 29.....		2		2	86
July 1.....	15	36	3	54	76	July 30.....		2	1	3	87
July 2.....	10	37	2	49	69	July 31.....		2		2	88
July 3.....	6	27		33	64	Aug. 1.....	1	1		2	88
July 4.....	1	31	1	33	63	Aug. 2.....		1		1	74
July 5.....	5	32	1	38	64	Aug. 5.....		1		1	80
July 6.....	6	35		41	66	Aug. 10.....		1		1	66
July 7.....	5	46		51	74						
July 8.....	4	26	4	34	71						
July 9.....	8	38		46	76						
						Total.....	305	1,116	43	1,464	.....

¹ ♀ Denotes specimens the sex of which was undetermined.

SPRING BROOD.

EMERGENCE OF SPRING-BROOD MOTHS.

In addition to the time of emergence and number of moths emerging each day, the sex of the moths was determined and recorded.

Moths began to emerge June 9, but did not emerge in any considerable numbers until June 22. (Fig. 2.) From this date emergence was heavy for about 10 days and then fell off gradually until the end of the emergence period on August 10.

RELATION OF EMERGENCE OF SPRING MOTHS TO GRAPE BLOOM.

The relation between the time of emergence and the blossoming period of grapes is of interest in substantiating earlier records.

TABLE X.—*Relation between the time of emergence of the spring brood of grape-berry moths and the period of grape bloom, Sandusky, Ohio, 1917.*

Period.	Dates inclusive.	Male moths.		Female moths.		Sex undetermined moths.		Total.	
		Num-ber.	Per-cent.	Num-ber.	Per-cent.	Num-ber.	Per-cent.	Num-ber.	Per-cent.
Before grape bloom.....	June 9-20.....	21	6.88	36	3.22	5	11.63	62	4.23
During grape bloom.....	June 21-July 1.....	179	58.68	522	46.77	17.	39.53	718	49.04
Ten days after bloom.....	July 2-11.....	52	17.05	313	28.04	8	18.60	373	25.47
Remainder of season.....	July 12-Aug. 10....	53	17.38	245	21.97	13	30.24	311	21.25
Total.....		305	.....	1,116	.....	43	.....	1,464	.....

The blooming period of grapes from June 21 to July 1 begins with the bloom of the Ives variety, one of the varieties grown commercially in the northern Ohio sections, and ends with the falling of bloom from the Catawba variety, also a commercial variety of importance in the sections studied. It is seen that less than 5 per cent of the total emergence occurred before the beginning of bloom, 50 per cent in the 10-day period during bloom, 25 per cent in the next 10-day period, and 21 per cent during the remainder of the season.



FIG. 2.—Diagram showing the time of emergence of spring-brood and first-brood moths of the grape-berry moth at Sandusky, Ohio, 1917.

A rather close correlation is evident between the rate of emergence and the daily mean temperatures.

PROPORTION OF SEXES OF SPRING-BROOD MOTHS.

TABLE XI.—*Proportion of sexes of spring moths of the grape-berry moth, Sandusky, Ohio, 1917.*

Sex of moths.	Number of moths.	Per cent of sexes.
Male.....	305	21.46
Female.....	1,116	78.54
Undetermined.....	43	.....
Total.....	1,464	100.00

The high percentage of female moths, as shown in Table XI, seems to account for the frequent heavy infestation by second-brood larvae after a comparatively light first-brood infestation.

PERCENTAGE OF EMERGENCE OF SPRING MOTHS.

TABLE XII.—*Percentage of emergence of spring moths of the grape-berry moth from hibernation under a leaf blanket in insectary yard, Sandusky, Ohio, 1917.*

Lot No.	Source of material.	Number of cocoons.	Number of moths emerged.	Emergence.
1	Collected as larvæ at Venice, Ohio, 1916.....	2,082	780	<i>Per cent.</i> 37.46
2	Collected as larvæ at Put in Bay, Ohio, 1916.....	1,493	236	15.80
3	Collected as larvæ at Kelleys Island, Ohio, 1916.....	2,371	231	9.74
4	Collected as larvæ at Venice, Ohio, 1916.....	82	12	14.63
	Total.....	6,028	1,259	20.88
	Average.....			

No explanation is offered for the variations in percentages of emergence from material collected at the different places. The material was all collected as larvæ in the infested grapes at similar times and kept under identical conditions after collection. That but 20 per cent of the cocoons formed withstood the winter under a light leaf blanket indicates that the natural mortality is considerable.

TIME OF DAY OF MOTH EMERGENCE.

Records were taken as opportunity offered on the time of day of moth emergence. These records were in the period July 8 to July 17 or about in the middle of the emergence period. They indicated in a general way that emergence began in the morning as soon as the heat of the day was felt and that practically all emergence took place between 6.30 a. m. and noon.

OVIPOSITION BY THE SPRING BROOD OF MOTHS.

A few records of oviposition were secured and are shown in Table XIII. These meager records serve only as an indication of the actual conditions prevailing.

TABLE XIII.—*Oviposition of spring moths of the grape-berry moth in rearing cages, Sandusky, Ohio, 1917.*

Observation No.	Number of moths.		Date of—			Days—		
	♂	♀	Emergence of moths.	First oviposition.	Last oviposition.	Before oviposition.	Of oviposition.	From emergence to last oviposition.
1.....	2	4	June 18	June 21	June 24	3	4	6
2.....	10	10	June 27	July 2	July 2	5	1	5
3.....	4	10	July 18	July 21	July 23	3	3	5
4.....	4	12	July 20	July 22	July 26	2	5	6
5.....	2	11	July 23	July 24	July 28	1	5	5
Average.....						2.8	3.6	5.4

PLACE OF OVIPOSITION ON THE VINE.

It was found that a vine of the Clinton variety set in a row of Concord was heavily oviposited upon before the Concord berries were formed. For use in the spacing of spray nozzles for the set-nozzle method of spraying, the place of oviposition on the vine seemed important. The place of oviposition on this one vine by the spring brood of moths was recorded and the data are presented in Table XIV. The vine was trained according to the fan system of grape training which is generally used for all varieties in the northern Ohio sections. In the fan system the vine growth which is trained to an upright trellis is annually renewed to within a short distance of the ground. The vines are cut back usually to from 2 to 4 canes and as many spurs each year; the canes are spread out and tied to the trellis obliquely, giving the shape of a fan.

TABLE XIV.—*Place of oviposition on vine by spring moths of the grape-berry moth, under natural conditions in vineyard, Venice, Ohio, 1917.*

Place on vine.	Dis- tances.	Num- ber of clusters.	Num- ber grapes bearing eggs.	Num- ber eggs.	Num- ber eggs per cluster.	Percentage of—	
						Depo- sition in this space.	Clusters in this space.
Between ground and first wire.....	<i>Inches.</i> 21	15	82	107	7	17	33.3
Between first and second wire.....	21-33	23	260	333	15	53	51.1
Between second and third wire.....	33-49	7	124	190	29	30	15.5
Total.....		45	466	630		100	100.0
Average.....					14.0		

The figures in Table XIV agree with the usual observation that the clusters near the ground are less heavily infested than those higher up on the vines. Thirty per cent of the deposition occurred between the middle wire and top wire, whereas but 15 per cent of the clusters were in that space. These figures likewise agree with field observations in that the heavy infestation is generally where the clusters are well covered with foliage, a condition which prevails near the top of the trellis.

In Table XV are presented records of the length of the incubation period of eggs of the first brood. The average number of days required for incubation was 4.39, the maximum 8 days, and the minimum 3 days. These figures include both insectary material and eggs collected in the vineyard when the date of deposition was known. In obtaining the eggs from the vineyards all eggs were removed from the vines each day.

FIRST GENERATION.

INCUBATION PERIOD OF FIRST-BROOD EGGS.

TABLE XV.—*Incubation period of first-brood eggs of the grape-berry moth, Sandusky, Ohio, 1917.*

Date of oviposition.		Date of hatching.	Number of larvæ.	Incubation period (in days).
June 21.	.....	June 28	4	7
30.	.....	July 4	28	4
30.	.....	July 5	18	5
30.	.....	July 6	8	6
30.	.....	July 8	1	8
July 1.	.....	July 5	24	4
1.	.....	July 6	6	5
1.	.....	July 7	2	6
1.	.....	July 6	18	4
1.	.....	July 7	2	5
21.	.....	July 24	1	3
22.	.....	July 25	2	3
23.	.....	July 26	1	3
23.	.....	July 28	1	5
24.	.....	July 28	2	4
24.	.....	July 30	4	6
26.	.....	July 29	2	3
26.	.....	July 30	3	4
26.	.....	July 30	27	4
27.	.....	July 31	11	4
Total.....			165	.....

Average length of incubation period, 4.39 days.

Maximum length of incubation period, 8 days.

Minimum length of incubation period, 3 days.

LENGTH OF FEEDING PERIOD OF FIRST-BROOD LARVÆ.

Records from the date of hatching until date of leaving fruit were secured on 70 larvæ in the insectary.

TABLE XVI.—*Length of feeding period of 70 first-brood larvæ of the grape-berry moth in grapes in rearing jars in the insectary, Sandusky, Ohio, 1917.*

Number of larvæ.	Larvæ hatched.	Larvæ left fruit.	Feeding period.	Number of larvæ.	Larvæ hatched.	Larvæ left fruit.	Feeding period.
			<i>Days.</i>				<i>Days.</i>
2.	July 3	July 21	18	2.	July 5	July 25	20
2.	do.	July 25	22	1.	do.	July 28	23
1.	do.	July 26	23	2.	July 5	July 29	24
1.	do.	July 29	26	1.	do.	July 31	26
1.	do.	July 30	27	1.	do.	Aug. 1	27
1.	do.	Aug. 5	33	1.	do.	Aug. 2	28
2.	July 4	July 19	15	2.	do.	Aug. 6	32
3.	do.	July 21	17	3.	July 6	July 22	16
2.	do.	July 22	18	6.	do.	July 23	17
6.	do.	July 23	19	1.	do.	July 26	20
2.	do.	July 24	20	1.	do.	July 27	21
1.	do.	July 27	23	1.	do.	July 30	24
1.	do.	July 28	24	1.	do.	July 31	25
2.	do.	July 29	25	1.	do.	Aug. 1	26
1.	do.	Aug. 5	32	1.	do.	Aug. 2	27
1.	July 5	July 19	14	1.	do.	Aug. 12	37
1.	do.	July 20	15	1.	July 7	July 21	14
3.	do.	July 21	16	1.	do.	July 25	18
4.	do.	July 22	17				
3.	do.	July 23	18	70			
2.	do.	July 24	19				

Average days, 20.62.

Maximum days, 37.

Minimum days, 14.

The average length of the feeding period is seen to be 20.62 days, the maximum 37 days, and the minimum 14 days. The records extended throughout the regular hatching period, and therefore reflect vineyard conditions closely.

LENGTH OF THE PREPUPAL PERIOD OF FIRST-BROOD INDIVIDUALS.

In Table XVII are given the dates of cocooning and the length of the period from the time of spinning the cocoon until pupation for individuals some of which were supplied with sprayed foliage and others with unsprayed foliage.

TABLE XVII.—*Time of cocooning and length of prepupal period of 231 individuals of the first brood of the grape-berry moth, Sandusky, Ohio, 1917.*

Foliage unsprayed:

Dates of cocooning—	Number of cocoons.
August 3.....	50
August 4.....	50
August 5.....	50
August 7.....	39
August 8.....	34

Foliage sprayed:

August 7.....	40
August 8.....	24

Dates of pupation.	Number of pupæ by days.						
Aug. 4.....	17	7	21	1	14	1	2
5.....	26	3	28	7	18	11	7
6.....	3	28	7	18	1	11	7
7.....							
8.....							
9.....							
10.....							
11.....							
12.....							
13.....							
Total number of pupæ.....	46	42	40	36	30	23	14
Dead in cocoons.....	4	8	10	3	4	17	10

TABLE XVIII.—*Summary of Table XVII. Length of prepupal period of 231 individuals of the first brood of the grape-berry moth, Sandusky, Ohio, 1917.*

Number individuals.		Prepupal period.
Cocooned on unsprayed foliage.	Cocooned on sprayed foliage.	
67	2	<i>Days.</i>
104	13	1
23	12	2
.....	12	3
.....	6	4
.....	4	5
194	37	.....
Average..... 1.77	2.9	.....
Maximum..... 3	5	.....
Minimum..... 1	1	.....

The data from Table XVII are summarized in Table XVIII. The average length of the prepupal period was 1.77 days, the maximum period 3 days, and the minimum 1 day, where unsprayed foliage was supplied. Where the cocoons were formed on sprayed foliage the average prepupal period was 2.9 days, the maximum 5 days, and the minimum 1 day. The spray material apparently had a repellent action, for in another experiment where both sprayed and unsprayed foliage were equally accessible to larvæ there were 226, or 63 per cent, of the total number of cocoons formed on unsprayed leaves and but 135, or 37 per cent, formed on sprayed leaves. Considerable mortality can be attributed to cocooning on sprayed leaves, since 194 pupæ were formed in 223 cocoons on unsprayed leaves, a mortality of 13 per cent as compared with the individuals that cocooned on sprayed leaves, where but 37 pupæ were formed in 64 cocoons, showing a mortality of 42 per cent.

TIME OF COCOONING OF FIRST-BROOD LARVÆ.

TABLE XIX.—*Time of cocooning of 2,447 larvæ of the first brood of the grape-berry moth, Sandusky, Ohio, 1917.*

Date of cocooning.	Number of cocoons.	Mean daily temperature.	Date of cocooning.	Number of cocoons.	Mean daily temperature.
		° F.			° F.
July 19.....	3	71	Aug. 14.....	51	74
July 20.....	2	76	Aug. 15.....	28	72
July 21.....	9	76	Aug. 16.....	36	74
July 22.....	9	76	Aug. 17.....	31	68
July 23.....	18	78	Aug. 18.....	58	68
July 24.....	10	80	Aug. 19.....	35	73
July 25.....	31	78	Aug. 20.....	58	78
July 26.....	44	80	Aug. 21.....	33	73
July 27.....	55	76	Aug. 22.....	33	72
July 28.....	73	72	Aug. 23.....	30	72
July 29.....	54	86	Aug. 24.....	21	66
July 30.....	128	87	Aug. 25.....	8	60
July 31.....	170	88	Aug. 26.....	9	62
Aug. 1.....	129	88	Aug. 27.....	17	73
Aug. 2.....	142	74	Aug. 28.....	5	68
Aug. 3.....	230	71	Aug. 29.....	5	62
Aug. 4.....	117	68	Aug. 30.....	1	64
Aug. 5.....	112	80	Aug. 31.....	6	64
Aug. 6.....	131	76	Sept. 1.....	4	75
Aug. 7.....	153	76	Sept. 2.....	8	69
Aug. 8.....	111	75	Sept. 3.....	1	67
Aug. 9.....	26	66	Sept. 6.....	1	66
Aug. 10.....	64	66	Sept. 8.....	1	62
Aug. 11.....	37	68			
Aug. 12.....	62	71			
Aug. 13.....	45	74			
			Total.....	2,447	.....

In Table XIX are given the complete records of cocooning for the first-brood larvæ. Cocooning began on July 19 and continued until September 8 with a distinctly high period from July 30 until August 8. The correlation with temperature is of interest, showing that as the mean temperature dropped below 70° F. there was a drop in the rate of cocooning.

LENGTH OF PUPAL STAGE OF FIRST-BROOD PUPÆ.

TABLE XX.—*Time of cocooning and length of pupal stage of 90 individuals of the first-brood pupæ of the grape-berry moth, Sandusky, Ohio, 1917.*

UNSPRAYED FOLIAGE FOR COCOONING.

Number of larvæ.				Date of pupation.	Date of moth emergence.	Days in pupal stage.		
♂	♀	♂	Total.			♂	♀	♂
.....	3	.....	3	Aug. 4	Aug. 16	0	12	.....
.....	4	.....	4	do	Aug. 18	.....	14	.....
2	7	.....	9	Aug. 5	do	13	13	.....
3	8	.....	11	do	Aug. 19	14	14	.....
1	2	.....	3	Aug. 7	Aug. 21	14	14	.....
.....	1	.....	1	do	Aug. 22	.....	15	.....
.....	1	.....	1	do	Aug. 23	.....	16	.....
.....	2	1	3	Aug. 8	Aug. 20	.....	12	12
1	8	.....	9	do	Aug. 21	13	13	.....
.....	1	.....	1	do	Aug. 22	.....	14	.....
.....	4	1	5	Aug. 9	Aug. 21	.....	12	12
1	2	.....	3	do	Aug. 22	13	13	.....
.....	5	.....	5	Aug. 10	do	.....	12	.....
2	5	.....	7	do	Aug. 23	13	13	.....
.....	2	.....	2	do	Aug. 24	.....	14	.....
.....	1	.....	1	Aug. 11	Aug. 22	.....	11	.....
.....	2	.....	2	do	Aug. 23	.....	12	.....
.....	1	.....	1	do	Aug. 27	.....	16	.....
10	59	2	71	Average	.....	13.4	13.11	12

SPRAYED FOLIAGE FOR COCOONING.

Number of larvæ.				Date of pupation.	Date of moth emergence.	Days in pupal stage.		
♂	♀	♂	Total.			♂	♀	♂
.....	1	.....	1	Aug. 8	Aug. 21	.....	13	.....
.....	1	.....	1	do	Aug. 22	.....	14	.....
.....	3	.....	3	Aug. 9	Aug. 23	.....	14	.....
.....	2	.....	2	do	Aug. 24	.....	15	.....
.....	1	.....	1	do	Aug. 25	.....	16	.....
.....	1	1	2	Aug. 10	Aug. 23	.....	13	13
.....	1	.....	1	do	Aug. 24	.....	14	.....
.....	1	.....	1	Aug. 11	Aug. 23	.....	12	.....
1	.....	.....	1	do	Aug. 27	16	.....	.....
.....	2	.....	2	Aug. 12	Aug. 26	.....	14	.....
.....	1	.....	1	do	Aug. 27	.....	15	.....
1	1	.....	2	do	Aug. 28	16	16	.....
.....	1	.....	1	do	Aug. 30	.....	18	.....
2	16	1	19	Average	.....	16	15	13

In Table XX the length of the pupal stage of 90 individuals is given. The average length of the stage was 13.4 days for males and 13.11 for females, all on unsprayed foliage. On sprayed foliage the average length of the period was 16 days for males and 15 for females.

LENGTH OF TIME SPENT IN THE COCOON BY FIRST-BROOD INDIVIDUALS.

The average length of time in the cocoon on unsprayed foliage is shown in Table XXI to be 15.52 days for males with 32 days as the maximum period and 9 days as the minimum. For females on unsprayed foliage 14.62 days was the average period, 32 days the

maximum, and 6 the minimum. On sprayed foliage males were in the cocoons 16.82 days as the average with 20 days as the maximum and 16 days the minimum period. Females were in the cocoons an average of 17.06 days with 27 days as the maximum and 13 days the minimum.

TABLE XXI.—*Length of time in cocoon of 1,318 individuals of the first brood of the grape-berry moth, Sandusky, Ohio, 1917.*

Sex of moths.	Number of moths.	Number of days in cocoon.		
		Average.	Maximum.	Minimum.
Male.....	226	15.52	32	9
Female.....	1,003	14.62	32	6
Undetermined.....	25	14.32	20	9
Total.....	1,254	14.78	32	6
Cocooned on sprayed foliage:				
Male.....	11	16.82	20	16
Female.....	53	17.06	27	13
Total.....	64	17.01	27	13

TIME OF EMERGENCE OF FIRST-BROOD MOTHS.

TABLE XXII.—*Time of emergence and sex of the first-brood moths of the grape-berry moth, Sandusky, Ohio, 1917.*

Date of emergence.	Number of moths.				Date of emergence.	Number of moths.			
	♂	♀	♂	Total.		♂	♀	♂	Total.
July 29.....	0	1	0	1	Aug. 26.....	8	42	0	50
30.....	0	1	0	1	27.....	12	50	3	65
31.....	1	6	1	8	28.....	7	45	1	53
Aug. 1.....	2	5	1	8	29.....	0	3	0	3
2.....	4	4	1	9	30.....	14	23	0	37
3.....	0	3	1	4	31.....	4	27	1	32
4.....	1	12	0	13	Sept. 1.....	5	31	1	37
5.....	4	8	0	12	2.....	2	27	1	30
6.....	1	16	0	17	3.....	10	23	0	33
7.....	7	20	0	27	4.....	0	6	0	6
8.....	4	33	3	40	5.....	5	3	0	8
9.....	0	5	0	5	6.....	4	20	2	26
10.....	2	25	1	28	7.....	1	5	0	6
11.....	7	26	0	33	8.....	1	8	0	9
12.....	7	43	0	50	9.....	4	14	0	18
13.....	2	14	0	16	10.....	1	7	0	8
14.....	20	66	0	86	11.....	0	2	0	2
15.....	19	110	1	130	12.....	1	3	0	4
16.....	24	128	8	160	13.....	2	2	0	4
17.....	10	41	3	54	14.....	0	1	0	1
18.....	21	85	0	106	15.....	1	2	0	3
19.....	19	49	4	72	17.....	0	1	0	1
20.....	6	55	1	62	18.....	1	4	0	5
21.....	23	105	2	130	19.....	0	1	0	1
22.....	19	61	0	80	20.....	1	2	0	3
23.....	13	66	4	83	21.....	2	0	0	2
24.....	9	44	1	54	22.....	0	1	0	1
25.....	5	27	0	32	Total.....	316	1,412	41	1,769

First-brood moths began to emerge on July 29 and emergence continued until September 22. It will be seen in figure 2 that the emergence was high for the entire period of August 12 to 28, varying with the mean daily temperature. It is also shown that the emergence

of the first-brood moths began before the spring brood emergence ended. This means that moths were emerging practically from grape bloom until grape harvest; the majority of all emergence, however, occurred in two well-defined periods, as shown graphically in figure 2.

PROPORTION OF SEXES OF FIRST-BROOD MOTHS.

TABLE XXIII.—*Proportion of sexes of first-brood moths of the grape-berry moth, Sandusky, Ohio, 1917.*

Sex of moths.	Number of moths.	Percentage of sexes.
Male.....	316	18.28
Female.....	1,412	81.72
Undetermined.....	41	.....
Total.....	1,769	100.00

The high percentage of female moths helps further to explain the occurrence of a large second brood of larvæ.

LIFE CYCLE OF THE FIRST GENERATION.

TABLE XXIV.—*Life cycle of the first generation of the grape-berry moth as determined from observations on the separate stages; summaries from the previous tables, Sandusky, Ohio, 1917.*

Summary from Table No.—	Stage.	Number of individuals.	Days of duration of stage.		
			Average.	Maximum.	Minimum.
XV	Egg stage.....	165	4.39	8	3
XVI	Length of feeding period of larvæ.....	70	20.62	37	14
XXI	Making of cocoon and pupal stage.....	1,254	14.78	32	6
XXI					
	Totallife cycle.....		39.79	77	23

The life cycle as here presented is seen to average 39.79 days with 77 days as the total of the maximums and 23 days as the total of the minimums. To the average of 39.79 should be added the period between moth emergence and oviposition, which is usually 3 days, thus making the total life cycle 42.79 days.

SECOND GENERATION.

INCUBATION PERIOD OF SECOND-BROOD EGGS.

One record only was secured concerning the incubation period of second-brood eggs, and that late in the season when the temperature was comparatively low. Twenty-two eggs were deposited on September 1, the black spot was evident on September 9, and the eggs hatched September 11, 10 days after oviposition.

TIME OF COCOONING OF SECOND-BROOD LARVÆ.

The dates on which larvæ were leaving the grapes and spinning cocoons are shown in detail in Table XXV.

TABLE XXV.—*Time of cocooning and number of cocoons of the second brood of the grape-berry moth, Sandusky, Ohio, 1917.*

Date of cocooning.	Dates of collection of larvæ.						
	August—			September—			
	30	30	30	2	3	3	6
Sept. 7.		1	1	1			
8.							
9.		1		1		1	
10.						1	
11.			1				
12.							
13.		2	1	2			
14.		1	2	1		1	
15.	1	1	1	1	1	2	
16.	1	1	2	2			
17.		2	2	1			
18.		1	1	1		2	
19.	1	1	3	1	1		
20.	2	2	9	2	1	7	
21.	2	1	5	3	1	1	1
22.	5	2	9	3	0	2	1
23.	0		5	2	3	3	1
24.	5	2	10	8	8	10	7
25.	5	4	8	6	8	3	4
26.	5	1	5	1	2	9	3
27.	8	3	6	6	8	7	5
28.	5	9	5	7	4	11	10
29.	7	2	3	4	6	3	7
30.	5	2	5	12	2	1	6
Oct. 1.	1	4	2	2	1	2	4
2.	8	2	4	3	6	2	4
3.	3	4	7	10	9	4	8
4.	2	1	5	6	4	5	6
5.	6	10	6	3		2	5
6.							
7.	4	2	2	3	2		1
8.		1		1	4	2	7
9.	1			2		2	1
10.		2		2	1		1
11.	2	2			5	2	2
12.					2	4	1
13.				1			
15.	4	7	3	9	10	6	3
16.	7	6	5	5	10	3	1
17.		3	1	3	1	2	3
18.		5	3	2	8	4	4
19.	4	3	6	5	13	5	14
20.							
21.					1		
22.					1		
23.							
24.							
25.							
26.							
27.							
28.					1		
29.							
30.		4				2	
31.							
Nov. 5.							
10.							
Jardiscontinued.....	Oct. 22	Nov. 10	Nov. 10	Nov. 21	Nov. 10	Nov. 10	Nov. 10

TABLE XXV.—*Time of cocooning and number of cocoons of the second brood of the grape-berry moth, Sandusky, Ohio, 1917—Continued.*

Date of cocooning.	Dates of collection of larvæ.					
	September—					
	6	6	9	9	9	12
Sept. 7		3				
8						
9						
10						
11						
12						
13		1			1	
14	1					
15	1			1	1	
16	1	1				
17				3		1
18						1
19	1	1				2
20	1					2
21		1			3	3
22	1	2		2	4	3
23	2	1				2
24	5	2		4	3	
25	4	1	1		4	7
26	1	2	2	2	1	4
27	4	3	3	3	14	7
28	4	5		2	11	8
29	4	2	1	3	14	2
30	4	4	3	2	4	5
Oct. 1	1	2		3	1	2
2	3	1	4	1	1	1
3	1		6	2	4	3
4	7	5	1	4	4	2
5	8	3	3	9		1
6						
7	12	5	2	2	4	4
8	4	2	1		7	2
9	1		1	1	2	
10	1					1
11					3	
12	1	4		2	4	
13		1				
15	15	8	1	4	20	3
16	12	6	3	2	8	1
17	1	2	3	1	6	
18	5	5		6	6	4
19	9	10		4	19	
20						
21		1				
22	2					
23	4			1		
24				1		
25		3				
26					2	
27						
28	3			1	3	
29					2	
30	4		2	2		
31						
Nov. 5					13	
10						
Jardiscontinued.....	Nov. 21	Oct. 31	Nov. 21	Nov. 21	Nov. 10	Nov. 10

TABLE XXV.—*Time of cocooning and number of cocoons of the second brood of the grape-berry moth, Sandusky, Ohio, 1917—Continued.*

Date of cocooning.	Dates of collection of larvæ.						
	September—						
	12	14	15	15	15	18	18
Sept. 7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.				1			
19.				2	1		
20.	3						
21.	2				2		
22.	2				1		
23.							
24.	4		3	4	2		
25.	2	1	3	8			1
26.	1		3	2	2		
27.	12		4	7	8		1
28.	4	1	6	11	10		1
29.	7	1	2	9	5	1	
30.	5		4	4	5		1
Oct. 1.	1	1	4	5	5		
2.			1	2			3
3.	7	4	11	13	16	1	3
4.	8	3	3	8		1	1
5.		3	9	14	6	2	
6.							
7.	7		3	9	5		
8.	2		3	3	2	1	2
9.					2		
10.			1	2	2		
11.	1		1	1	3		
12.	2		1	6	2	1	
13.	15		9	17	4		2
14.	10		8	11	5	1	2
15.	3		3	3	3		
16.	2		2	10	11	4	
17.	4						
18.			12	27	11		
19.				1	1		
20.					1		
21.	1	2			2		
22.							
23.							
24.							
25.				1			
26.							
27.							
28.	2			9	6		
29.	4			4			
30.			1	3	5	2	2
31.							
Nov. 5.							
10.							
Jar discontinued 1.	Nov. 21	Nov. 22	Nov. 21	Nov. 26	Nov. 21	Nov. 21	Nov. 21

TABLE XXV.—*Time of cocooning and number of cocoons of the second brood of the grape-berry moth, Sandusky, Ohio, 1917—Continued.*

Date of cocooning.	Dates of collection of larvae.						
	September—						
	18	22	22	22	29	29	29
Sept. 7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.		2					
26.	1		1				
27.	1	2	1	1			
28.		5					
29.	1	3					
30.	1	3					
Oct. 1.		1					
2.	1		1		1		
3.		3		2	3	6	
4.	1	2		6	1		3
5.		2	2	2		1	2
6.							
7.		3		1		6	4
8.		7		2	2	2	3
9.		3					
10.		1					
11.					1		
12.				1			
15.	1	6	3	2	2	1	1
16.	1	6	1	1	1	10	9
17.		1	2	1		3	5
18.	1	5	5	6	3		
19.							
20.	3	4	7	6	4	13	7
21.	1						
22.				1			
23.							
24.						1	
25.				1	1		
26.							
27.							
28.			2				
29.							
30.	1			1		1	
31.							
Nov. 5.							
10.							
Jar discontinued.....	Nov. 9	Nov. 9	Nov. 9	Nov. 9	Nov. 6	Nov. 9	Nov. 9

TABLE XXV.—*Time of cocooning and number of cocoons of the second brood of the grape-berry moth, Sandusky, Ohio, 1917—Continued.*

Date of cocooning.	Dates of collection of larvæ.						Total cocoons.	Mean daily temperature.
	Oct. 2 to Nov. 4.							
Sept. 7.....							6	58
8.....							0	62
9.....							3	62
10.....							1	52
11.....							1	52
12.....							0	58
13.....							7	65
14.....							6	65
15.....							10	66
16.....							8	64
17.....							9	64
18.....							7	64
19.....							14	67
20.....							29	69
21.....							26	60
22.....							37	59
23.....							20	57
24.....							78	59
25.....							72	59
26.....							48	64
27.....							119	66
28.....							123	58
29.....							88	60
30.....							80	52
Oct. 1.....							42	48
2.....							50	52
3.....							134	58
4.....							93	54
5.....							99	50
6.....							0	44
7.....							82	50
8.....							61	45
9.....							16	43
10.....	1						15	45
11.....							26	45
12.....	1	1					36	40
13.....							2	38
15.....	1	4	1	2	1		177	55
16.....	1						144	50
17.....		1		2			55	49
18.....							121	64
19.....		3	1	1	1		124	47
20.....	2					1	100	40
21.....						4	6	43
22.....	1						7	41
23.....							8	40
24.....						1	6	42
25.....							6	42
26.....							2	44
27.....							0	42
28.....						3	32	44
29.....							10	48
30.....	3		1	1	4	7	46	31
31.....				1			1	32
Nov. 5.....						3	3	46
10.....							13	50
Jar discontinued.....	Nov. 21	Nov. 21	Nov. 21	Nov. 21	Nov. 21	Nov. 21	2,309	

PERCENTAGE OF COCOONING PREVIOUS TO AND DURING GRAPE HARVEST.

Table XXVI shows the time of cocooning of the larvæ that left the fruit in the fall of 1917. This does not necessarily indicate, however, that all the larvæ left the fruit before the end of grape harvest, for observation showed that a considerable part of the second brood of larvæ were only partially grown at the time of harvest and that large numbers of larvæ actually left the vineyards in the fruit. No accurate method of determining what part of the total

number of larvæ were thus removed occurred to the writer, but an estimate of one-third would be conservative. This had a decided influence on the number of overwintering pupæ and subsequent infestation in 1918.

TABLE XXVI.—Percentage of cocooning previous to and during grape harvest, Sandusky, Ohio, 1917.

Time.	Date.	Number of cocoons.	Percentage of total.
Previous to beginning of Concord harvest.....	To Oct. 8.....	1,291	55.91 *
During Concord harvest.....	Oct. 8-18.....	653	28.28
Previous to end of Concord harvest.....	To Oct. 18.....	1,944	84.19
Previous to beginning of Catawba harvest.....	To Oct. 22.....	2,174	94.16
Previous to end of Catawba harvest.....	To Nov. 10.....	2,309	100.00

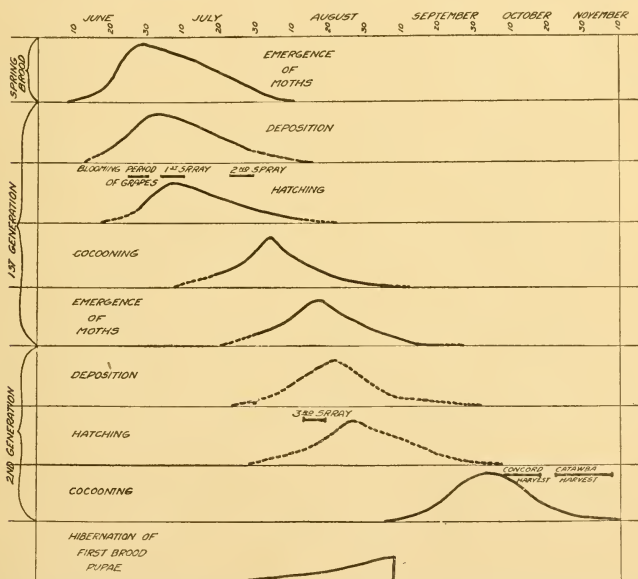


FIG. 3.—Diagram showing summary of the life-history data for 1917 of the grape-berry moth. Solid lines indicate actual records and dotted lines indicate occurrence of stages as observed in the field and computed from the average length of period.

SUMMARY OF SEASONAL-HISTORY STUDIES IN 1917.

A summary of the data presented in the preceding tables is shown graphically in figure 3.

It should be kept in mind in applying this diagram to future seasons that the season of 1917 was later than the average for northern Ohio and was unseasonably wet and cold throughout the fall.

SEASONAL-HISTORY STUDIES, 1918.

SPRING BROOD.

TIME OF EMERGENCE AND SEX OF MOTHS OF THE SPRING BROOD.

Table XXVII shows the dates of emergence of spring-brood moths and the number of each sex that emerged each day.

TABLE XXVII.—*Time of emergence and sex of moths of the spring brood of the grape-berry moth, Sandusky, Ohio, 1918.*

Date of emergence.	Number of moths.				Mean daily temperature.	Date of emergence.	Number of moths.				Mean daily temperature.
	♂	♀	♂	Total.			♂	♀	♂	Total.	
May 22	1	-----	-----	1	74	June 17	8	26	-----	34	70
25	1	3	-----	4	72	18	3	16	-----	19	65
26	0	2	2	4	78	19	2	6	1	9	66
27	0	4	1	5	78	20	1	6	-----	7	61
28	1	2	-----	3	66	21	2	14	-----	16	70
29	4	9	-----	13	64	23	-----	12	-----	12	62
30	3	11	2	16	72	24	1	13	1	15	66
31	2	6	2	10	78	25	4	10	-----	14	66
June 1	12	21	3	36	81	26	-----	11	1	12	66
2	12	17	7	36	75	27	1	7	1	9	76
3	14	26	2	42	68	28	2	8	2	12	74
4	6	17	2	25	74	29	3	13	-----	16	74
5	9	20	-----	29	67	30	-----	8	-----	8	75
6	12	22	2	36	73	July 1	-----	4	-----	4	62
7	4	17	-----	21	66	2	-----	1	-----	1	62
8	5	6	-----	11	64	3	-----	2	1	3	72
9	10	25	1	36	69	4	1	2	2	5	73
10	10	20	-----	30	66	5	-----	2	-----	2	76
11	5	6	1	12	70	6	-----	2	1	3	72
12	7	30	1	38	72	7	-----	4	-----	4	63
13	2	12	-----	14	62	9	-----	1	-----	1	64
14	6	22	1	29	66	12	-----	1	-----	1	66
15	3	8	-----	11	64	Total ...	161	482	38	681	
16	4	7	1	12	72						

The early opening of the season hastened the grape growth and moth emergence was correspondingly early. The first emergence took place on May 22 and emergence in considerable numbers began on June 1. A rather high rate of emergence prevailed for about a two-week period and then gradually subsided. (Fig. 4.)

PROPORTION OF SEXES OF MOTHS OF THE SPRING BROOD.

TABLE XXVIII.—*Proportion of sexes of moths of spring brood of the grape-berry moth, Sandusky, Ohio, 1918.*

Sex of moths.	Number of moths.	Percentage of sexes.
Male.....	161	25.04
Female.....	482	74.96
Undetermined.....	38	.....
Total.....	681	100.00

The proportions as shown in Table XXVIII are comparable with the figures in Table XI on the spring brood of moths in 1917. It appears that the preponderance of females is the usual condition.

PERCENTAGE OF EMERGENCE OF SPRING MOTHS.

The overwintering material was collected and kept under the same conditions as that of the previous winter. The percentage of emergence was slightly higher but still indicating a high rate of mortality.

TABLE XXIX.—Percentage of emergence of spring moths of the grape-berry moth, Sandusky, Ohio, 1918.

Source of material.	Number of cocoons.	Number of moths emerged.	Emergence.
Collected as larvæ at Venice, Kelleys Island, Put in Bay, and Dover, Ohio.	2,544	681	Per cent. 26.70

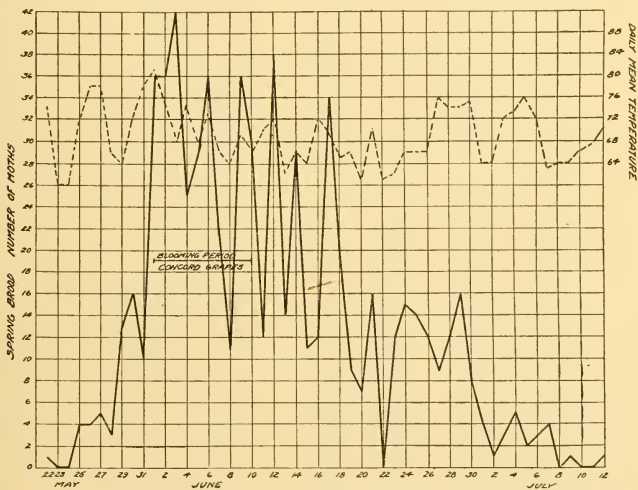


FIG. 4.—Diagram showing emergence of spring brood of moths of the grape-berry moth at Sandusky, Ohio, 1918.

The winter of 1917-18 was the most severe of 47 years on record at the Sandusky station of the United States Weather Bureau, and included intensely cold periods with little covering. This is of importance in connection with the foregoing records, for it must be concluded that the grape-berry moth pupæ are very resistant to severe winter conditions.

FIRST GENERATION.

TIME OF COCOONING AND LENGTH OF TIME IN THE COCOON OF FIRST-BROOD INDIVIDUALS.

TABLE XXX.—*Time of cocooning and length of time in cocoon of the first brood of the grape-berry moth, Sandusky, Ohio, 1918.*

Number of larvæ.	Date larvæ left fruit.	Moths emerged.	Days.		Number of larvæ.	Date larvæ left fruit.	Moths emerged.	Days.	
			In co-coon.	Total.				In co-coon.	Total.
1	July 7	July 23	16	16	5	Aug. 2	Aug. 13	11	55
4	July 9	do	14	56	9	do	Aug. 14	12	108
1	do	July 24	15	15	1	do	Aug. 15	13	13
3	July 10	do	14	42	6	Aug. 3	Aug. 14	11	66
3	July 11	do	13	39	1	do	Aug. 16	13	13
2	July 12	do	12	24	12	Aug. 4	Aug. 15	11	132
3	do	July 25	13	39	1	do	Aug. 16	12	12
2	July 13	July 24	11	22	1	do	Aug. 17	13	13
1	do	July 25	12	12	1	do	Aug. 18	14	14
2	do	July 26	13	26	1	do	Aug. 20	16	16
1	do	July 27	14	14	1	Aug. 5	Aug. 17	12	12
3	July 14	July 26	12	36	3	Aug. 6	Aug. 18	12	36
2	do	July 27	13	26	10	do	Aug. 19	13	130
5	July 15	do	12	60	5	do	Aug. 20	14	70
1	do	July 28	13	13	1	do	Aug. 21	15	15
1	do	July 29	14	14	3	Aug. 7	Aug. 18	11	33
2	July 16	July 27	11	22	9	do	Aug. 19	12	108
3	do	July 28	12	36	12	do	Aug. 20	13	156
2	do	July 29	13	26	3	do	Aug. 21	14	42
1	do	Aug. 2	17	17	2	do	Aug. 22	15	30
9	July 17	July 29	12	108	2	do	Aug. 23	16	32
2	do	July 31	14	28	1	do	Aug. 26	19	19
7	July 18	July 29	11	77	15	Aug. 8	Aug. 20	12	180
5	do	July 30	12	60	18	do	Aug. 21	13	234
11	do	July 31	13	143	11	do	Aug. 22	14	154
1	July 19	July 29	10	10	1	do	Aug. 23	15	15
8	do	July 31	12	96	5	Aug. 9	Aug. 21	12	60
3	do	Aug. 1	13	39	22	do	Aug. 22	13	286
1	do	Aug. 2	14	14	12	do	Aug. 23	14	168
1	July 20	July 30	10	10	1	do	Aug. 25	16	16
3	do	July 31	11	33	2	Aug. 10	Aug. 21	11	22
9	do	Aug. 1	12	108	4	do	Aug. 22	12	48
4	do	Aug. 2	13	52	10	do	Aug. 23	13	130
3	July 21	do	12	36	1	do	Aug. 24	14	14
9	do	Aug. 3	13	117	1	do	Aug. 25	15	15
7	do	Aug. 4	14	98	3	Aug. 11	Aug. 23	12	36
16	July 22	do	13	208	4	do	Aug. 24	13	52
14	do	Aug. 5	14	196	8	Aug. 12	do	12	96
1	do	Aug. 6	15	15	9	do	Aug. 25	13	117
18	July 23	Aug. 5	13	234	1	do	Aug. 27	15	15
11	do	Aug. 6	14	154	3	Aug. 13	Aug. 26	13	39
6	July 24	do	13	78	2	do	Aug. 27	14	28
1	July 25	Aug. 7	13	13	3	do	Aug. 28	15	45
8	do	Aug. 8	14	112	2	Aug. 14	Aug. 27	13	26
1	July 26	Aug. 6	11	11	2	do	Aug. 28	14	28
8	do	Aug. 8	13	104	4	Aug. 15	do	13	52
10	do	Aug. 9	14	140	2	do	Aug. 29	14	28
2	July 27	Aug. 8	12	24	1	Aug. 16	Aug. 28	12	12
7	do	Aug. 9	13	91	1	do	Aug. 29	13	13
3	do	Aug. 10	14	42	1	Aug. 17	Aug. 28	11	11
9	July 28	do	13	117	2	do	Aug. 29	12	24
6	do	Aug. 11	14	84	2	do	Aug. 30	13	26
1	July 29	Aug. 10	12	12	1	do	Aug. 31	14	14
6	do	Aug. 11	13	78	1	Aug. 18	do	13	13
1	July 30	Aug. 10	11	11	1	Aug. 19	Sept. 2	14	14
7	do	Aug. 11	12	12	1	Aug. 20	Sept. 4	15	15
3	July 31	Aug. 12	12	84	1	Aug. 21	Sept. 5	15	15
1	do	Aug. 13	13	39	1	Aug. 22	Sept. 6	15	15
2	do	Aug. 14	14	14	1	Aug. 23	do	14	14
1	Aug. 1	Aug. 12	11	22					
2	do	Aug. 13	12	24					
1	do	Aug. 14	13	13					
Total, 522					6,731				

Average days, 12.9.

Maximum days, 19.

Minimum days, 10.

It is seen in Table XXX that first-brood larvæ began to leave the fruit July 7 and continued to leave until August 23. The table does

not show as well defined a high period as usually exists; the comparative dearth of rearing material is thought to account for this condition.

TIME OF EMERGENCE AND SEX OF FIRST-BROOD MOTHS.

The dates of emergence and number of moths are shown in Table XXXI and in graph in figure 5. Attention is directed to the rise in emergence on August 4 and 5 and then the sudden drop without another high point until August 20. The writer accounts for this, partly by a comparable drop in the cocooning in the period previous

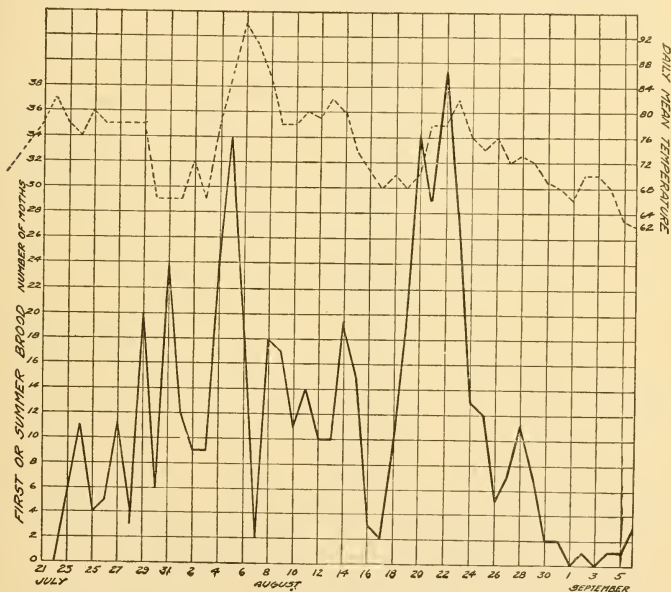


Fig. 5.—Diagram showing dates of emergence and number of moths of the grape-berry moth at Sandusky, Ohio, 1918.

and partly by an actual killing of the pupæ by excessive heat that prevailed on August 5 to 8. On August 5 the official Weather Bureau records showed a maximum temperature of 94° F., on the 6th 105°, on the 7th 100°, and on the 8th 97°. When emergence dropped off suddenly on August 6 and 7 examination of the pupæ then about to transform to moths showed considerable mortality. Extensive records could not be taken without destroying the material that was to serve for further life-history studies.

TABLE XXXI.—*Time of emergence and sex of first-brood moths of the grape-berry moth, Sandusky, Ohio, 1918.*

Date of emergence.	Number of moths.				Mean daily temperature.	Date of emergence.	Number of moths.				Mean daily temperature.
	♂	♀	♂	Total.			♂	♀	♂	Total.	
July 23		6		6	°F. 78	Aug. 15	1	14		15	74
24	1	9	1	11	76	16		3		3	71
25	1	3		4	80	17	1	1		2	68
26		5	0	5	78	18		9		9	70
27	1	9	1	11	78	19	2	17		19	68
28		2	1	3	78	20	7	25	2	34	70
29	2	15	3	20	78	21	6	20	3	29	78
30	1	3	2	6	66	22	14	23	2	39	78
31	6	16	2	24	66	23	9	17	2	28	82
Aug. 1		9	3	12	66	24	3	9	1	13	76
2	2	7		9	72	25	2	9	1	12	74
3	2	7		9	66	26	1	4		5	76
4	5	18		23	78	27	1	6		7	72
5	4	26	4	34	85	28	1	10		11	73
6	4	15		19	94	29	2	5		7	72
7	1	1		2	91	30		2		2	69
8	8	10		18	86	31		2		2	68
9	6	9	2	17	78	Sept. 2	1			1	70
10	4	5	2	11	78	4		1		1	68
11	2	12		14	80	5		1		1	63
12		9	1	10	79	6	1	2		3	62
13	2	8		10	82						
14	2	15	2	19	80	Total..	106	399	35	540	

PROPORTION OF SEXES OF FIRST-BROOD MOTHS.

TABLE XXXII.—*Proportion of sexes of first-brood moths of the grape-berry moth, Sandusky, Ohio, 1918.*

Sex of moth.	Number of moths.	Percentage of sexes.
Male.....	106	21.00
Female.....	399	79.00
Undetermined.....	35	-----
Total.....	540	100.00

The proportion of sexes as shown in Table XXXII maintains the preponderance of females that has been shown in previous tables.

OVIPOSITION BY FIRST-BROOD MOTHS.

A single record of oviposition and incubation was secured. In a jar containing 14 male moths and 12 female moths, all of which emerged on August 22, 5 eggs were deposited on August 26 and hatched on September 2. The period from emergence to oviposition was therefore 4 days and the incubation period 7 days.

NUMBER OF TRANSFORMING AND OVERWINTERING INDIVIDUALS OF FIRST BROOD.

In Table XXXIII are presented the data on the overwintering first-brood individuals.

It will be seen that the first larva to hibernate left the fruit on August 2 and that the number gradually increased as the season progressed.

TABLE XXXIII.—*Number of transforming and overwintering individuals of the first brood of the grape-berry moth, Sandusky, Ohio, 1918.*

Number of larvæ.	Date larvæ left fruit.	Number of—			
		Moths emerged.	Pupæ hibernating.	Larvæ parasitized.	Dead.
1.	June 30				1
1.	July 7	1			
5.	July 9	5			
4.	July 10	3			1
4.	July 11	3			1
5.	July 12	5			
10.	July 13	6		1	3
7.	July 14	5		1	1
11.	July 15	7		3	1
8.	July 16	7		1	
23.	July 17	11		3	9
25.	July 18	23		1	1
18.	July 19	13			5
26.	July 20	17			9
29.	July 21	19			10
44.	July 22	31		1	12
41.	July 23	29		1	11
34.	July 24	6			28
21.	July 25	9			12
22.	July 26	19			3
19.	July 27	13		1	5
20.	July 28	15			5
12.	July 29	7			5
4.	July 30	2			2
14.	July 31	11			3
11.	Aug. 1	5			6
24.	Aug. 2	15	1		8
9.	Aug. 3	7			2
28.	Aug. 4	16			12
37.	Aug. 5	1	1		35
52.	Aug. 6	6			33
55.	Aug. 7	32	1		22
67.	Aug. 8	45	2		20
48.	Aug. 9	40	2		6
27.	Aug. 10	18	1		8
12.	Aug. 11	7	1		4
29.	Aug. 12	18	3		8
13.	Aug. 13	8	1		4
11.	Aug. 14	4	4		3
8.	Aug. 15	6	1		1
3.	Aug. 16	2			1
6.	Aug. 17	6			
5.	Aug. 18	2	3		
1.	Aug. 19	1			
3.	Aug. 20	1	2		
5.	Aug. 21	1	3		1
7.	Aug. 22	1	5		1
10.	Aug. 23	1	7		2
6.	Aug. 24		6		
9.	Aug. 25		9		
Total, 894.....		523	53	13	355

TABLE XXXIV.—*Summary of Table XXXIII, showing number and percentage of first brood individuals of the grape-berry moth that transform.*

Observations on—	Number.	Per cent.
Number of larvæ.....	894	100.0
Number of moths emerged.....	523	58.5
Number of hibernating pupæ.....	53	5.9
Number of parasitized larvæ.....	13	1.4
Number of dead individuals.....	305	34.1

Table XXXIV summarizes the data in Table XXXIII and shows that but 5.9 per cent of all the recorded larvæ hibernated, that 58.5 per cent emerged as moths the same season, that 1.4 per cent of the larvæ were parasitized when collected, and that 34.1 per cent of all died.

SECOND BROOD.

TIME OF COCOONING OF SECOND-BROOD LARVÆ.

Table XXXV presents the cocooning data in detail.

TABLE XXXV.—*Time of cocooning and number of cocoons of the grape-berry moth, Sandusky, Ohio, 1918.*

Date of cocooning.	Dates of collections of larvæ.					
	August—			September—		
	14	19	24	6	14	21
Aug. 15.	2					
16.	3					
17.	2					
18.	3					
19.						
20.	1	2				
21.	1	3				
22.		6				
23.	3	7				
24.	1	5				
25.	7	2				
26.	5	8	5			
27.	3	3	1			
28.	5	8	2			
29.	2	8				
30.	2	2	6			
31.	1	4	1			
Sept. 1.	1	1	2			
2.	2	2	3			
3.	1	3	4			
4.	4	8	9			
5.	1	2	2			
6.		4	3			
7.		5	2	1		
8.		10	3	3		
9.	1	3	7	9		
10.	1	8	2	7		
11.		6		2		
12.	1	3	6	6		
13.		1	2	3		
14.	1	3	7	4		
15.		6	10	10	2	
16.		5	3	4	4	
17.		1	2	8	1	
18.		1	1		1	
19.		1		3	1	
20.			1	1		
21.				1		
22.		1	2			1
23.		1	9	6	2	1
24.			2	8	2	3
25.		2	11	9	4	6
26.				2	2	1
27.			2	7	2	
28.			2	6	3	5
29.			4	5	3	4
30.		1	1	3	2	1
Oct. 1.				3	1	1
2.			2	5	3	2
3.			1	4	5	3
4.				2	2	1
5.			1	5	1	1
6.			2	2	2	4
7.					1	1
8.				1		
9.				2		
10.			1			2
11.						
12.						2
13.					1	
14.						
15.						
16.						2
17.						
18.						
19.						
20.						
21.						
22.				1		
23.				1		
24.						
25.						
26.						
27.						
28.						
29.				1		
30.						
31.						
Dates jars discontinued.						
	Oct. 1	Oct. 21	Oct. 21	Nov. 1	Oct. 26	Nov. 1

TABLE XXXV.—Time of cocooning and number of cocoons of the grape-berry moth, Sandusky, Ohio, 1918—Continued.

Date of cocooning.	Dates of collections of larvæ.				Total cocoons.
	Septem- ber—	October—			
		28	14	15		16
Aug. 15					2
16					3
17					2
18					3
19					
20					3
21					4
22					6
23					10
24					6
25					9
26					18
27					7
28					15
29					10
30					10
31					6
Sept. 1					4
2					7
3					8
4					21
5					5
6					7
7					8
8					22
9					20
10					18
11					8
12					16
13					6
14					15
15					28
16					16
17					12
18					3
19					5
20					2
21					1
22					5
23					19
24					15
25					32
26					5
27					11
28					16
29		21			37
30		20			28
Oct. 1		9			14
2		17			29
3		11			24
4		7			12
5		34			42
6		20			30
7		3			5
8		3			4
9		9			11
10		6			9
11		4			4
12		1			3
13		3			4
14		3			3
15					0
16		2			4
17			2		9
18		10	4	3	26
19		3	7	2	7
20		2	2	5	14
21		1	4	6	15
22				1	2
23			2	1	4
24		3	8	6	18
25		1	4	4	14
26			1	1	2
27			1	5	8
28			2	1	6
29			2		3
30			1		1
31		1			1
Dates jars discontinued.	Nov. 1	Nov. 1	Nov. 1	Nov. 1	842

Cocooning began as early as August 15 and continued until October 31.

PERCENTAGE OF COCOONING PREVIOUS TO AND DURING GRAPE HARVEST.

TABLE XXXVI.—*Percentage of cocooning previous to and during grape harvest, Sandusky, Ohio, 1918.*

Time.	Date.	Number of cocoons.	Percentage of total.
Previous to beginning of Concord harvest.....	To Sept. 20.....	343	40.73
During Concord harvest.....	Sept. 20-Oct. 10...	342	40.62
Previous to end of Concord harvest.....	To Oct. 10.....	685	81.35
Previous to beginning of Catawba harvest.....	To Oct. 8.....	670	79.57
Previous to end of Catawba harvest.....	To Oct. 26.....	821	97.50
After Catawba harvest.....	To Nov. 1.....	21	2.50

The data in Table XXXV are summarized in Table XXXVI and emphasize similar records for the seasons of 1916 and 1917. From these records of three seasons involving a large quantity of larvæ regularly collected it must be concluded that a very large part of the second-brood larvæ leave the fruit previous to and during the early part of grape harvest.

MISCELLANEOUS RECORDS.

In the course of the life-history studies some observations were made that have a bearing on the habits of the insect and the development of the different stages.

ADULT.

The pupæ formed in the fall of 1916, from which moths emerged in the spring of 1917, were kept through the spring emergence period of 1918 to determine if any pupæ lived over and emerged the second spring. No moths emerged from this material the second year.

In an effort to approach natural conditions for moths in confinement dilute strained honey was supplied in the rearing jars. The usual observation was that the moths were not attracted to the food, but would feed if they came in contact with it. In one case when no new food had been supplied for six days, upon placing water on the sand in the bottom of the cage two moths immediately went 1½ inches to the water and appeared to drink of it.

The adults seldom are seen in the vineyards during the day, and throughout these investigations, though the writer was in heavily infested vineyards almost daily, moths were rarely observed. In one case a moth was seen resting on a young cluster of grape buds, another was observed on the upper side of a grape leaf, and a third adult was seen in flight about the lower part of a grapevine. It alighted on a cane, ran into the angle of a small stub on the cane, and rested there, its head in the angle.

MATING.

Mating was observed but once, this in the insectary on July 19, 1917, at 2.45 p. m. The moths emerged the day previous and the jar contained 4 males and 10 females with a sprig from a grapevine bearing a grape leaf and cluster. The moths were on the bottom of the jar, not mounted, but with their bodies in opposite directions, the posterior parts touching.

OVIPOSITION.

The following observations on oviposition were made in a heavily infested part of a large vineyard on June 30, 1917. Oviposition began about sundown or 6.30 p. m. When the moths first appeared they fluttered nervously about the vines, alighting seemingly at random, generally upon clusters, though often upon stems or leaves. Upon finding a cluster a moth would walk rapidly about upon a grape berry, covering practically the entire surface. Finally becoming quiet she would flex the abdomen until its tip touched the berry. During the process the abdomen twitched or shook slightly but the tip was at no time lifted and then replaced. The deposition of the egg required less than a minute's time but was not instantaneous. Upon completion of the deposition of a single egg the moth usually flew nervously away from the cluster. The following exception occurred among four depositions observed. A moth alighted upon a grape and oviposited immediately without any preliminary inspection and upon completion walked directly onto the next grape in the same cluster and repeated the operation.

The spring brood of moths deposits a considerable percentage of the eggs near the attachment of the grape to the cluster, and the first-brood moths seem frequently to select a place on the underside of the cluster, away from the light.

Repeated observation has shown that the moths discriminate between sprayed and unsprayed grapes as places for oviposition. This was most marked in one experimental vineyard in 1916. Four rows had been left unsprayed and the adjoining rows sprayed, with the exception of the side of one row next to the checks. This row was thoroughly sprayed from one side by the trailer method and the grape clusters well covered on that side. About a third of the surface of the clusters remained unsprayed and deposition by first-brood moths was apparently as heavy on this unsprayed surface as on the adjoining check rows, whereas practically no eggs were deposited on the sprayed side of the same clusters. This observation led to continued study on the same point and it was substantiated repeatedly during the investigations. That eggs are deposited to some extent on the sprayed surface has been shown by infestation of sprayed plats.

That early blooming varieties of grapes are more heavily infested than mid-season varieties has been known generally among grape

growers. During these investigations the writer has been led to believe that the moths normally prefer to deposit their eggs on the formed grapes rather than on the unopened buds. This was strikingly shown in the case of the Clinton vine on which oviposition records were taken for Table XIV. On this single Clinton vine, growing in a row of the Concord variety with the Ives variety close by, were 994 grapes bearing eggs on June 29. Subsequently 630 more eggs were recorded on this one vine. Careful search was made on adjoining vines of the other varieties and not until the grapes were well formed could eggs be found, whereas heavy oviposition continued on the Clinton vine. Repeatedly vines of the Shrides variety, the earliest of any to bloom in northern Ohio, have been heavily infested with larvæ when adjoining vines of the Concord and Catawba varieties bore no eggs and were not infested. This condition also prevailed where several rows of the Clinton or other early blooming varieties paralleled rows of the later blooming varieties. In years of heavy infestation it is advisable to spray the early blooming varieties earlier than the midseason varieties.

EGG.

A single observation was made on the issuance of the larva from the egg, on August 9, 1916. When first observed, the head of the larva was just through the eggshell and 2½ minutes more were required for the larva to free itself entirely from the shell. The larva did not consume the empty eggshell.

LARVA.

Mention is often made of the habit of the first-brood larvæ to web the young grape clusters before or during bloom. In but one instance during three seasons has the writer seen these webbed clusters in the grapes of the mid-season blooming period. Webbing frequently occurs in the Delaware variety which is in full bloom a few days after the Concords and just at the time when the spring-brood moths are emerging in large numbers, as shown in figures 2 and 4. This same condition exists with the Norton variety, which blooms very late.

The grape-berry moth larvæ occasionally feed on grape leaves in the rearing cages even when grapes are present, and in at least one case a larva developed from about one-half size to maturity by feeding in this way.

LARVÆ FEEDING ON PHYLLOXERA GALLS.

On August 25, 1916, and again on October 2, 1917, vines of the Clinton variety of grape were observed which were heavily infested by the leaf form of the grape phylloxera. Examination of the phylloxera galls showed that they had been eaten into and in some cases much of the gall actually consumed. On these same leaves with the galls were thin white silken webs containing larvæ which

closely resembled the grape-berry moth larvæ. A quantity of the leaves were collected on August 25, 1916, and placed in battery jars containing no other food for the larvæ. The larvæ at the time of collection varied from less than half-grown to nearly mature specimens. The leaves dried out but the larvæ completed their feeding and cocooned in the leaves, a total of 79 cocoons being secured. Pupæ from this material were identified by August Busck of the U.S. Bureau of Entomology as *Polychrosis viteana* Clem. The pupæ were kept over winter under outdoor conditions and 12 moths emerged the following spring. In a single instance an empty eggshell was found on the under surface of the leaves close to a phylloxera gall. In the observation made on October 2, 1917, about 1 leaf in 5 had the web formed by the larvæ which were feeding on the galls. In no case could it be definitely determined whether the phylloxera in the galls were consumed with the gall tissue. No leaf feeding other than on the galls occurred with the larvæ under observation.

CANNIBALISM AMONG GRAPE-BERRY MOTH LARVÆ.

To determine if the larvæ would be cannibalistic with a restricted food supply the following experiment was conducted: From field-collected second-brood larvæ, 40 between 4 and 7 mm. in length were taken and divided into two lots of 20 each on September 14, 1917. One lot was placed in a jar with 20 grapes and the other lot was similarly placed with but 5 grapes. Grape leaves were provided in both jars for pupation of the larvæ. On November 22 the following results were recorded: In the lot where 20 grapes were provided, 15 cocoons had been formed and 2 full-grown live larvæ were present. Considerable substance remained in the grapes. Careful search for the other 3 individuals failed to locate them. In the lot where but 5 grapes were supplied, 5 cocoons had been formed, 2 dead and 2 live larvæ were present, or a total of 9 accounted for. A careful search was made for the head shields of the other 11 larvæ but they were not to be found. All the pulp from all the grapes had been consumed. From this single experiment it appears that cannibalism exists among the larvæ when the food supply is restricted and may occur even with sufficient food present for all.

LARVÆ NOT KILLED BY LOW TEMPERATURES.

The resistance of grape-berry moth pupæ to severe winter conditions has been noted. On October 30, 1917, a severe freeze occurred in northern Ohio, sufficient to freeze Concord and Catawba grapes. The lowest temperature recorded at the Sandusky station of the United States Weather Bureau on October 30 was 25° F., 26° on October 31 and November 1, and 28° on November 2. When recording the results of spraying experiments at Put-in-Bay, Ohio,

on November 5, and at Kelleys Island, Ohio, on November 7, live larvæ were plentiful in the grapes and no case was found where the larvæ had been killed by the freeze. In the insectary at Sandusky after a minimum temperature of 23° F. had been recorded, larvæ continued to leave the grapes and spin cocoons. Live larvæ persisted in the insectary on December 3, 1917, after a minimum temperature of 17° F. had been recorded.

LARVA SPINNING ITS COCOON.

On July 9, 1916, a first-brood larva was observed making its cocoon. When first observed the characteristic flap had been cut in the leaf but was not folded. The process observed was the turning over and tying down of the flap. The larva began at one end and by rapid movements of its head from the free edge of the flap to its place of attachment it gradually drew the flap over, the body of the larva resting on the flap, and eventually inclosed in it. The entire process observed occupied 35 minutes.

PARASITISM.

Considering the large numbers of individuals observed during these investigations the total amount of parasitism was very low, particularly among first-brood pupæ taken for the following emergence records.

That some parasitism of first-brood pupæ occurred is shown in Table XXXVII.

TABLE XXXVII.—*Percentage of parasitism of field collected first-brood grape-berry moth pupæ from Venice, Ohio, 1917.*

Date of collection.	Number of cocoons collected.	Number of parasites emerged.	Percentage of parasitism.
July 26.....	18	0	0
July 28.....	34	8	20.58
July 30.....	32	1	3.12
Aug. 1.....	41	11	26.82
Aug. 4.....	64	2	3.12
Aug. 6.....	47	8	17.02
Aug. 8.....	51	12	23.53
Aug. 10.....	35	12	34.28
Aug. 20.....	8	0	0
Do.....	31	4	12.90
Total.....	361	58	16.06
Average.....			16.06

The parasitism of field-collected pupæ is seen to vary from 0 to 26 per cent with an average of 16 per cent for pupæ collected between July 26 and August 20.

In a single instance, September 8, 1916, eggs of the berry moth were found which were parasitized to an appreciable extent. A total of 760 eggs were collected on 11 clusters, of which 236, or 31 per cent,

were parasitized. The parasite was not determined but was thought to be the same as recorded by Johnson and Hammar¹ at North East, Pa., in 1906, *Trichogramma pretiosa* Riley.

SUMMARY.

The present account of the life history of the grape-berry moth in northern Ohio is based upon a series of studies made in 1916, 1917, and 1918.

In the course of a year the grape-berry moth in northern Ohio produces one full brood and a partial second, the second brood of larvæ being much larger and more destructive than the first.

The grape-berry moth passes the winter in the pupal stage in cocoons in old grape leaves under the grape trellis. Under a leaf blanket approximating conditions in a protected part of a vineyard the mortality among the pupæ was 80 per cent during the winter of 1916-17 and 76 per cent during the winter of 1917-18.

The first moths emerge in the spring about 10 days before grapes begin to bloom but emerge in greatest numbers during and immediately following the period of grape bloom. In 1917 but 4 per cent emerged previous to bloom, 50 per cent during grape bloom, 25 per cent in the 10-day period following bloom, and the remaining 21 per cent later in the season. Moths begin ovipositing about 4 days after emergence and the eggs hatch in from 3 to 10 days, with 5 days as the average length of the egg stage.

The first-brood larvæ feed in the young grapes for a period of from 14 to 37 days, and the average length of the feeding period was 20.6 days in 1917. At the end of the feeding period the larvæ leave the grapes and go to tender grape leaves on the vines in which they spin their cocoons. The prepupal period lasted for from 1 to 3 days and averaged 1.77 days with the first brood in 1917, and lasted for from 3 to 7 days and averaged 4.15 days with the second brood in 1916. The pupal period varied from 11 to 16 days and averaged 13 days for first-brood pupæ in 1917. The total period in the cocoon varied from 6 to 32 days with an average period of 15 days.

The life cycle of the first generation in 1917, taken as a total of the average length of the separate stages, was 39.79 days. The total of the maximums was 76 days and of the minimums 23 days.

The incubation period of second-brood eggs varied from 4 to 10 days with 5.1 days as the average period. The feeding period of second-brood larvæ was from 16 to 36 days and averaged 24.18 days in 1916. All other records have given this period as about 40 days which is probably nearer the average condition than the figures presented here.

¹ Johnson, Fred, and Hammar, A. G. The grape-berry moth. U. S. Dept. Agr., Bur. Ent. Bul. 116. pt. II, p. 39. 1912.

Second-brood larvæ begin to leave the fruit early in the fall, August 22, 1916, August 15, 1918, September 7, 1917, but leave in greatest numbers just previous to and during the early part of the harvest season. In 1916, 77 per cent of the larvæ left the fruit previous to the beginning of the Concord harvest and 90 per cent previous to the beginning of the Catawba harvest. In 1917 corresponding figures were 56 per cent and 94 per cent.

In each brood of moths the females occur in much larger number than the males, the proportions being 21 per cent males, 79 per cent females in the spring brood, 1917; 18 per cent males, 82 per cent females in the summer brood, 1917; 25 per cent males, 75 per cent females in the spring of 1918; and 21 per cent males and 79 per cent females in the summer brood of 1918. A small part of the first-brood larvæ do not transform to moths the same season but hibernate and emerge as moths, the following spring. In 1918 this amounted to 5.9 per cent of the total number recorded. Of the same lot of larvæ but 1.4 per cent were parasitized.

Mating and egg deposition were observed during these investigations. The habit of the grape-berry moth larvæ of feeding on grape leaf galls formed by the grapevine phylloxera was noted. Extreme resistance of the larvæ to low temperature was also noted, live larvæ persisting after a minimum temperature of 17° F. had occurred. Parasitism was very low and of little consequence as a control during these investigations.

Control measures recommended are cultural methods which will leave the overwintering pupæ exposed to the elements as much as possible. Satisfactory control was effected by two spray applications by the "trailer" or hand method of spraying. The first application should be made 3 to 5 days after the young grapes set and the second when the grapes first touch in the clusters.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

December 9, 1920

THE RED-BANDED LEAF-ROLLER.¹

By F. H. CHITTENDEN, *Entomologist in Charge, Truck Crop Insect Investigations.*

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INTRODUCTION.

A small greenish caterpillar, about three-fourths of an inch long when mature, and known as the red-banded leaf-roller^{b, c}, attacks the foliage of beans, sweet potato, asparagus, strawberry, raspberry, and various other crops, and at times attracts considerable attention. Such was the case in October, 1919, when the species was abundant in and near the District of Columbia.

October 9, 1919, the writer, in company with W. H. White, Bureau of Entomology, noted that the foliage of sweet potato at College Park, Md., showed considerable injury near the petioles or leaf-stems manifested by large, irregular, more or less elongate holes between the ribs. Some of these were made by a leaf-miner and had been cut out earlier in the season, but many were the work of this leaf-roller which had tied or joined the leaves in different manners. In some cases the leaves were folded between the midrib and the next rib, and the larva had gouged out a hole about twice this length and half the width. Where the leaves were joined the surface at one end was lined with silk. In many cases the larva joined the leaves near the middle of one side and cut out a similar hole, constructing its tent-like shelter at one end.

A very considerable proportion of the top leaves had been attacked by this species and the leaf-miner, but at the time these observations were made there were many more parasites and parasitic cocoons present on the leaves than larvæ.

¹ *Eulia velutinana* Walk.; family Tortricidae, order Lepidoptera.

October 27, 28, and 31, 1919, Miss Marion T. Van Horn collected this leaf-roller in war gardens at Potomac Park in the District of Columbia on sweet potato and on lima and other beans. The leaf-rollers were found in particular abundance where sweet potato and bean vines grew together. Half a dozen or more larvæ were frequently found in a hill, while many rolled and webbed leaves proved that the larvæ had been quite plentiful earlier in the season.

It was noted that toward the end of October and the early days of November the larvæ rolled the leaves from the sides and from the ends, making a more substantial shelter than when they were immature, and lined it with white silk preparatory to pupation.

The fact is noteworthy that this species was more numerous on sweet potato and beans in 1919 than in previous years, the first being an unrecorded food plant. In former years this species has sometimes occurred in raspberry quite as abundantly as the strawberry leaf-roller (*Ancylis comptana* Froehl.).

DESCRIPTIVE.

THE MOTH.

The moth which produces the red-banded leaf-roller is a small, mottled brown form with the fore-wings having an expanse of between a little more than half to nearly three-fourths of an inch (13 to 19 mm.). The pattern of the fore-wings varies to a considerable extent. In the female there is a large, median, dark reddish-brown band running obliquely from the middle of the costa to the tornus, a subapical, irregular, smaller one, and a third postero-basal patch of the same color. The lighter parts of the wings are pale reddish brown, arranged in irregular bands with borders of pale yellow and silver white. The hind-wings are infuscated, with wide white borders and an inner ciliary line. The abdomen is dark gray and the tufts of the head and thorax are reddish brown.

The females are usually considerably larger than the males, with rather more distinct and larger patterns.

The female moth is shown in figure 1 with expanded wings at *a*, and in natural position, when at rest with the wings folded, at *b*. Technical descriptions have been given in so many available publications that a more complete one than here given may be dispensed with for the present purpose. The synonymy is as follows:

Eulia velutinana Walker.

Cacoccia (?) *velutinana* Walker, 1863, List Lep. Brit. Mus., p. 314.

Cacoccia triferana Walker, 1863, l. c., p. 314.

Tortrix incertana Clemens, 1865, Proc. Ent. Soc. Phila., v. 5, p. 138.

Tortrix lutosana Clemens, 1865, l. c., p. 138.

Lophoderus triferanus Walker, Walsingham, 1879, Lep. Het. Brit. Mus., pt. iv, p. 15.

Eulia triferana Walker.

THE EGG.

The eggs resemble those of other leaf-rolling species of Tortricidae. They are much flattened to the surface upon which they are deposited, and to which they tightly adhere, are scale-like in appearance, and overlap, are very pale dull-yellowish in color, the surface finely granulate and moderately shining. The length is about 0.8 mm. to 0.85 mm. (0.03 inch) and the width 0.7 mm.

THE LARVA.

The larva is shown in figure 1, *c*. It suggests at first glance *Epagoge sulfureana* Clem., with which it agrees in many respects. It is, however, larger and readily distinguishable by the lighter and more nearly uniform color of the head and thoracic plate; the head is perceptibly yellowish or light brownish in life but the plate can scarcely be distinguished from the general color of the body.

The two lobes are closely joined at the middle, being separated by a very narrow strip of lighter color. The two lateral piliferous spots below the thoracic plate are pale. In *Dichelia*, on the other hand, the head and thoracic plates and lateral thoracic spots are a decided

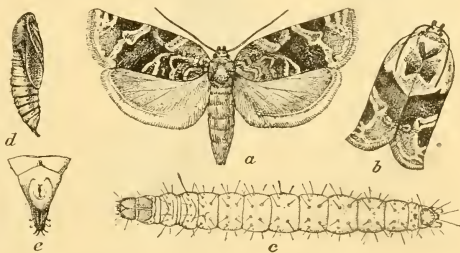


FIG. 1.—Red-banded leaf-roller (*Eulia relutinana*): *a*, Female moth; *b*, moth with wings folded at rest; *c*, larva, dorsal view; *d*, pupa, lateral view; *e*, tip of abdomen of pupa, showing abdominal hooks. *a-d*, About three times natural size; *e*, more enlarged.

brown, the latter well chitinized and with a darker posterior margin.

The form is elongate cylindrical, about 8 or 9 times as long as wide when extended. The piliferous tubercles are larger and more prominent, but in their arrangement as well as in the vestiture itself they are very like *Epagoge*.

The entire surface of the body except the head is in life a rather pale grass-green much mixed with yellow, the dorsal surface being a little lighter and the head less greenish and tinged lightly with brown. In alcohol the dorsal surface, including head and thorax, becomes pale yellow, except at the sutures, where the remaining white color of the body is visible. Partially grown larvæ (8 mm. long) are uniform pale green.

The thoracic legs are just perceptibly darker, as a rule, than the abdomen, and the apices of the tarsi are infuscated.

The form is less flattened than in *Dichelia*, otherwise the shape of the body and of the head, thorax, and legs is very similar. The last segment is of the appearance shown in figure 2 at *c*, the anal plate presenting no special characters worthy of notice, although the extreme apex is remarkable on account of the comb-like process, consisting of 6 spines, with which it is armed.

The length of the largest full-grown larva is about 0.7 inch (18 to 19 mm.); the width, 0.8 inch (2 to 2.2 mm.). Some larvæ are considerably smaller.

The head and first and second thoracic segments are shown from above, much enlarged, in figure 2, *a*. Figure 2, *b*, shows an abdominal segment with proleg from the side.

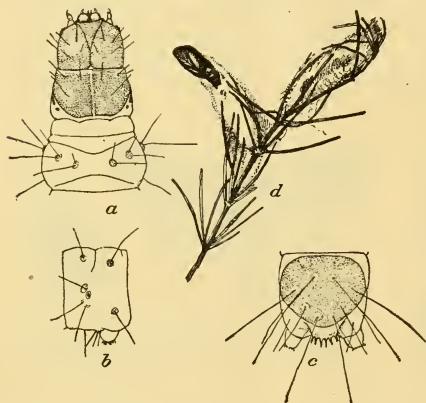


FIG. 2.—Red-banded leaf-roller: *a*, Head and first two thoracic segments, dorsal view; *b*, third abdominal segment, lateral view; *c*, last abdominal segment, from above, showing anal plate and comblike tip; *d*, sprig of asparagus showing web of larva and chrysalis working its way out of web at left. *a*, *b*, *c*, Much enlarged; *d*, somewhat enlarged.

THE PUPA.

The pupa appears still more like that of *Epagoge sulfureana*. It is a little stouter on the average, the greatest width being across the wing-pads. (See fig. 1, *d*.) The last ventral segment, shown from below (fig. 1, *e*), also bears a pair of lateral and two pairs of terminal hooked processes as in *Epagoge* (eight in all).

The length is about 0.4 inch (8 to 10 mm.), the width is about 0.1 inch (2.2 to 3 mm.).

DISTRIBUTION.

Eulia velutinana is native to this country, and has been known for a considerable number of years from Maine to Texas.

It is well established in the Transition Life Zone and available records show greater abundance there and in the northern portion of the Upper Austral, although it is to be found also in the Lower Austral. Possibly it has been introduced into California through commerce with the East. (See map, fig. 3.)

INJURIES AND OCCURRENCES.

The records of the Bureau of Entomology show a wide diversity in larval food habits. The earliest are those of Dr. C. V. Riley made at St. Louis, Mo., or in that vicinity. The rearing of this insect on grapes was noted July 28, 1870, and the issuance of the moth from larvæ found on raspberry was noted August 4, 1876.

June 11, 1879, pupæ were found rolled up in the leaves of red clover, from which the moths emerged June 13. June 23 another moth issued from larvæ feeding on clover June 10, and the following day an additional specimen issued from a larva feeding on white clover. August 11 a moth was reared from a pupa found spun up on a leaf of apple August 7. October 12 the larva was found on aspen and the moth issued December 10.



FIG. 3.—Distribution of the red-banded leaf-roller.

June 15, 1882, the moth was reared from larvæ found on apple in the District of Columbia.

Moths were reared June 7, 1885, from larvæ taken on Solidago.

June 12, 1886, the moth was reared from larvæ taken on roses, and on July 27 from others taken on privet and on willow. There is also a note on the rearing of this species June 7, 1886, from the galls of a species of Phylloxera.

This species was reared by Mr. Albert Koebele at Los Angeles County, Calif., from material found on the leaves of orange, April 24, 1888; and on July 26, 1893, specimens were received from Mr. J. G. Barlow, Cadet, Mo., with the report that the larvæ were found boring in the tips of chrysanthemums.

August 13, 1897, the moth was reared from larvæ which had been feeding on violet in the District of Columbia.

There are also three notes on specimens collected by Miss Mary E. Murtfeldt, presumably at her home at Kirkwood, Mo., recording the occurrence of the larvæ on lobelia, smartweed, and asparagus.

May 15, 1898, isolated individuals in the larval stage were observed on the twisted-up leaves contiguous to immature buds of blackberry at River View, Md., the buds having been eaten into in many cases and prevented from blooming. During July larvæ were observed in considerable abundance at Marshall Hall, Md., also on blackberry and on the webbed-up leaves of pigweed (*Amaranthus retroflexus*). Moths issued August 9 and 10.

July 14 to 25, 1899, larvæ were found at Alexandria, Va., by Mr. T. A. Keleher, Bureau of Entomology, on cabbage, raspberry, and cultivated honeysuckle. Moths began to issue July 31. September 26 the larva was received with the information that the material had been obtained from Mr. C. H. Stuart, Newark, N. Y., and that the species was infesting popcorn. Mr. Stuart made the statement that 27 per cent of the ears of popcorn were infested, and that 37 per cent of the corn on each infested ear were destroyed by this caterpillar, an unusual instance of injury.

During the latter part of May and early June the moths of this species were several times observed in the field, and June 13 the moths were seen at rest upon cabbage and rhubarb. On the former plant a deserted pupal skin was found on the under surface of the leaf directly below the point where the moth had been resting, and the midrib was found to have been eaten to the extent of 6 or 8 inches along both sides. Subsequently other cabbage plants were found to have been similarly affected, and a pupa was found in one of these from which the moth afterwards issued.

October 5 larvæ were observed on celery at Washington, D. C., and later the same species was found at work on celery and still more abundantly on asparagus at Brookland, D. C. Later it was observed on parsley, strawberry, and raspberry at Cabin John, Md., and on potted geranium at Washington, D. C. On celery and parsley the larvæ were apparently less abundant, as on these plants they are more difficult to see without close scrutiny, since they web up the leaves very neatly and in such a manner as not readily to attract attention. On asparagus, however, the webs are quite noticeable and could be seen at some little distance. In the formation of their temporary homes, the larvæ use an abundance of silk, often distorting the asparagus stems by drawing them together.

In every instance above mentioned the adults were reared from the material obtained.

In the manner of their attack the larvæ of this species do not differ markedly from those of the sulphur leaf-roller. In work upon corn the young blades are either folded lengthwise so as to form a cylindrical case or simply rolled up as are all other plants when attacked.

This moth was reared December 31, 1903, from larvæ found on cabbage by E. N. Burke, Macon, Ga. The same date the moth was reared from larvæ found on okra in the District of Columbia.

The species was found in great abundance on asparagus in the District of Columbia in the latter days of September, 1904, the larvæ at this time being full grown or nearly so. Many deserted nests were also found, as well as the usual number of spider nests, which so closely resemble those made by the leaf-roller.

Beginning March 23, 1907, the adults of this species issued from foliage of elderberry collected at Arlington, Va., September 3, 1906.

During the last week of October, 1907, Mr. C. H. Popenoe, Bureau of Entomology, observed specimens of this green larva working on species of ground-cherry (*Physalis*) at Arlington, Va.

The following year he observed the larvæ at Topeka, Kans., working in the tips of ripe ears of sweet corn under the husk, lining the tunnels with silk.

Most of the foregoing records were made from observations of the writer and his associates in the Bureau of Entomology, and there are also some others which need not be mentioned in detail. These include the finding of the larvæ working on zinnia, syringa, hollyhock, snowball, and magnolia. There is also record of attack to catalpa at Welch, W. Va.

BIOLOGIC NOTES.

The larvæ taken on asparagus by Miss Murtfeldt were found October, 1882, and the moths of this lot issued February 21, 1883.

In the writer's recent experience with this insect in the neighborhood of Washington, D. C., nearly all of the larvæ that were obtained in the autumn were approaching maturity during the first week of October, and some had formed their webs for pupation by the middle of that month. By the close of the month all the individuals observed had transformed to pupæ, the moths beginning to issue January 23 and continuing until March 22. In every case that came under observation pupation took place within the larval web or in another close to the place where the larva had been feeding.

The moths kept under unnatural conditions in a warm room issued in January.

A larva obtained from Newark, N. Y., previously mentioned, began forming its cocoon September 28, and the following day appeared to have finished, but further observation showed that it had not entirely completed it, since more silk was added apparently from day to day. It was noted that the larva, before transforming to pupa, cut out a round hole of about the same size or a little larger than the pupa itself. Transformation to this stage took place the first week in October, the moth issuing in January, having been

kept with others in a warm room. There is a singular agreement in the times of pupation and issuance of the specimens at Washington and in Missouri, and of the one individual observed from New-ark, N. Y.

In the District of Columbia, and probably elsewhere as well, hibernation takes place exclusively in the pupal state.

From the facts that larvæ have been observed in the open on May 15, that pupæ have been found as early as the second week in June, and that moths have issued during the third week, it was readily surmised that the moths which have hibernated as pupæ appear some time in April and lay eggs for the first generation. The moth was collected during the latter days of April in 1900.

The moths from the first new generation emerge for the most part during the second and third weeks of June, and of the next generation the last of July and the first two weeks of August, the third generation developing in October and early November and wintering as previously mentioned.

It seems to be fairly certain that there are at least two, and probably three generations annually in a climate like that of the District of Columbia and Missouri, and probably no more than two in a more northern latitude like that of the New England States.

From a female captured June 14, eggs were obtained in two masses of about 45 and 65 respectively upon the two following days, and the larvæ hatched in 11 days. The weather was rather cooler than seasonable during this time. A portion of the eggs were placed in a large rearing jar with growing strawberry plants, and the imago obtained July 23, the larval and pupal stages having been passed in 28 days. The weather was extremely hot (80° to 90° F. indoors) during the latter portion of this period, and the pupal stage must have been about 6 days, which would give 22 days or about 3 weeks as the larval period.

Of the larvæ which were collected in the vicinity of the District of Columbia in October, 1919, all had transformed to pupæ by the middle of November and the first moth issued April 15 of the following year, others continuing to issue for a few days thereafter. April 19 an imago was captured at light in the open.

It will thus be seen that the pupal or resting stage of this species for the District of Columbia and vicinity is an even 5 months, leaving 7 months for the active or working periods of the species.

HISTORY OF THE SPECIES.

The species was given its specific name in 1863 by Walker (1)², who described it under the name of *Cacoecia* (?) *velutinana*.

² Italic figures in parentheses refer to "Literature cited," p. 13.

C. triferana, described at the same time, is now considered a synonym, the former name having been given to the male, the latter to the female. In 1865 it was again described as new by Clemens (2) as *Tortrix incertana*. Four years later it was redescribed under the same name by Robinson (3, p. 278). With this last description illustrations of both sexes were furnished.

In 1870 our first account of the habits of this leaf-roller was published by Dr. A. S. Packard (4, p. 40). It is mentioned as the red-banded cranberry Tortrix or "cranberry worm" and is treated in connection with insects affecting the cranberry in Massachusetts, the account including a description of the adult and a short description of the pupa. This paper was republished in later years (5, 6).

In Dr. C. H. Fernald's catalogue of the Tortricidæ, published in 1882-83 (7, p. 15), some new localities are added for the species and several new food plants, the latter on the authority of Miss Murtfeldt. Besides cranberry the list includes elm, soft maple, oak, apple, rose, beans, and *Gnaphalium polycephalum*.

It was not until 1885 that any extensive account of the insect was published. This was by Dr. S. A. Forbes (8) and is in connection with insects found attacking corn in Illinois. Strawberry and clover are added to the list of food plants.

In 1890, Mr. F. M. Webster (10) included this species in a list of insects observed at Lafayette, Ind., affecting salsify. The same year Packard (11) wrote again concerning this insect. The following year Prof. Lawrence Bruner (12, p. 267) mentioned this species briefly in an account of corn insects.

In 1893 Miss M. E. Murtfeldt (13) referred to this species as one which webs and curls the leaves of Osage orange. In 1898 the writer (15) mentioned it briefly in connection with insects that attack asparagus. There followed Dr. Otto Lugger's short description (16), in which it was called the apple Lophoderus.

In 1901 the writer (17) recorded the feeding of the larva on violet in the District of Columbia. The same year Felt (18, p. 998) recorded the depredations of this insect on green popcorn at Newark, N. Y.

In 1904 Slingerland (19; 20, p. 47) stated that this insect was observed with the grape-berry moth on clusters of blossoms and recently set fruit of grape, and was quite often found at the same destructive work. In reviewing the known food plants, he records attack to Solidago and dogbane and mentions *Urogaster canarsiae* Ashm. as a parasite.

In 1905 Forbes (21) again mentions this species as an enemy of Indian corn, and the year following Felt (22) includes it in a report on insects affecting park and woodland trees.

FOOD PLANTS.

The red-banded leaf-roller is nearly omnivorous, its food plants comprising many botanical orders. The list follows:

Asparagus, beans, sweet potato, cabbage, horse-radish, celery, parsley, rhubarb, salsify, tomato, sweet corn, pepper, okra, ground cherry (*Physalis*), blackberry, raspberry, and strawberry among truck crops; chrysanthemum, geranium, rose, lobelia, violet, snowball, syringa, hollyhock, zinnia, privet, and honeysuckle comprise the list of ornamental plants. Other plants affected are clover, field corn and popcorn, cranberry, elderberry, grape, orange, apple, plum, elm, maple, oak, laurel oak, aspen, willow, magnolia, catalpa, balsam fir, and Osage orange. The larva also attacks pigweed (*Amaranthus retroflexus*), goldenrod (*Solidago* spp.), smartweed, dogbane, *Solanum* sp., and *Gnaphalium polycephalum*.

NATURAL ENEMIES.

The red-banded leaf-roller is no exception to a somewhat general rule that larvæ which conceal themselves from view in rolled and

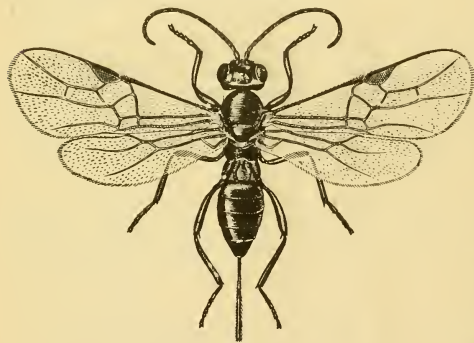


FIG. 4.—*Microbracon* sp., a parasite of the red-banded leaf-roller.

webbed leaves and similar places of shelter are the more subject to parasitic attack. The following list of parasites is in evidence:

Exochus curvator Fab., an ichneumonid, was reared by the writer August 7, 1900, from the host larva collected at Camerons Mills, Va.³

Epiurus indagator Walsh was reared from this leaf-roller on oak at Kirkwood, Mo., November 7, 1878.

An ichneumonid parasite allied to *Pimpla* was reared from material received from Cadet, Mo., in July, 1893, previously mentioned. (Dept. Agr. No. 5861°.)

Lampronota pleuralis Cress. was reared at St. Louis, Mo., November 7, 1878.

Limnerium sp. is mentioned by F. M. Webster as having been reared with this leaf-roller and two others on salsify.

³ Identified by Ashmead, who also identified practically all of the other species mentioned unless otherwise noted.

Opius foersteri Gahan, a braconid, wrongly determined as *Opius mellipes* Prov., and published under that name in *Insect Life* (9), was reared from material received from Kirkwood, Mo., September 25, 1881.

Epirhyssalus atriceps Ashm., a minute yellow braconid, was reared from its host July 1, 1907, breeding on rose and collected by Mr. I. J. Condit at Pataskala, Ohio.⁴

Microbracon sp. (fig. 4) was reared from material collected by Mr. M. R. Smith at Plymouth, Ind.

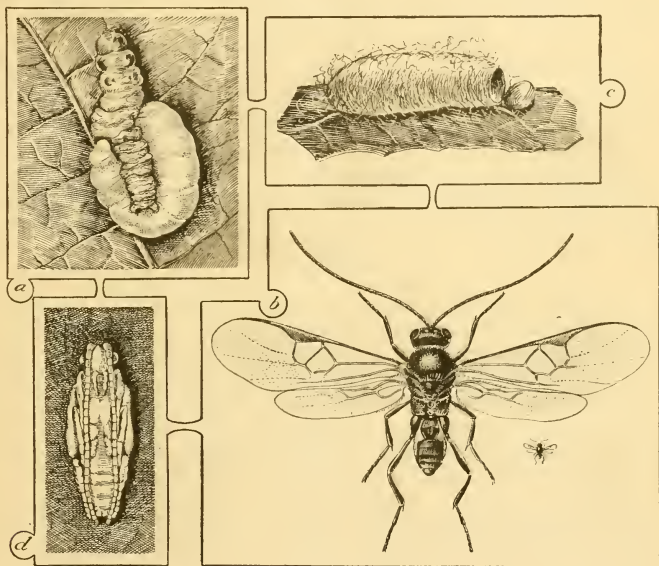


FIG. 5.—*Apanteles canarsiae*, a parasite of the red-banded leaf-roller: *a*, Larva feeding on leaf-roller larva; *b*, adult parasite; *c*, cocoon; *d*, pupa. All much enlarged. (Strauss.)

Smicra deliva Cress., a chalcidid, was reared by the writer during the last week of July and first week of August from raspberry leaves infested by this leaf-roller from Camerons Mills, Va.

Smicra torvina Cress. was reared with the foregoing.

Apanteles canarsiae Ashm. (fig. 5) was reared from this leaf-roller by Slingerland (20) in New York, and is somewhat better known as a parasite of the grape leaf-folder (*Desmia funeralis* Hbn.) and some other species.

⁴ Identified by Mr. J. C. Crawford.

Phorocera parva Bigot,⁵ a tachina fly, is reported as a parasite of this leaf-roller by Coquillett (14).

CONTROL.

The red-banded leaf-roller is seldom sufficiently abundant to warrant artificial methods for its control. Since it conceals itself in leaves, rolled or bound together, it would appear difficult to reach it with insecticides, but as it must issue from this shelter to feed on surrounding leafage it can then be reached by the application of arsenicals. The best time to apply these is soon after the eggs are laid. Arsenate of lead is the standard insecticide, used at about 2 or 3 pounds to 50 gallons of water and applied as a spray.

The webbed leaves can be readily detected after a little practice, and when infestation is not too heavy these can be clipped and burned, or they may be pinched so as to crush the larvæ within.

Early fall plowing and burning over the garden after the crop is off, either in fall or early spring, are two farming methods which, if vigorously practiced, will undoubtedly help greatly toward holding this insect in check. They should both be put into practice in case of infestation.

SUMMARY.

The foliage of beans, sweet potato, asparagus, strawberry, raspberry, and various other crops is subject to attack by a small greenish caterpillar about three-fourths of an inch long when mature, known as the red-banded leaf-roller, which rolls the leaves in various ways, according to the nature of the plant attacked, and breeds continuously throughout the growing season, from April to November.

It is native to this country, where it enjoys a wide distribution from Maine to Texas and has been found in California.

The species has been studied in the District of Columbia and vicinity. Hibernation takes place exclusively in the pupal state, which occupies a period of 5 months, leaving 7 months for the active or working stage. The ascertained period of the egg stage is 11 days, of the larva 22 days, and of the pupa a minimum of 6 days. There are at least two and probably three generations annually in the climate where observed.

Several natural enemies, mostly parasites, attack this species.

The red-banded leaf-roller is seldom sufficiently abundant to warrant artificial methods for its control, and since it conceals itself in rolled-up leaves, it is difficult to reach with insecticides. It can, however, be reached with a spray of lead arsenate, inasmuch as it issues from this shelter to feed on surrounding leafage. Clipping the webbed leaves from the affected plants, early fall plowing, and burning over affected areas after the crop is off, will help to hold the insect in check.

⁵ Identification by Coquillett.

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UNITED STATES DEPARTMENT OF AGRICULTURE
BULLETIN No. 918

Contribution from the Bureau of Entomology, L. O. HOWARD, Chief
in collaboration with the Federal Horticultural Board
C. L. MARLATT, Chairman

Washington, D. C.

PROFESSIONAL PAPER

April 19, 1921

REPORT ON INVESTIGATIONS OF THE PINK
BOLLWORM OF COTTON IN MEXICO

By

U. C. LOFTIN, Entomological Assistant, K. B. McKINNEY,
Scientific Assistant, and W. K. HANSON,
Plant Quarantine Inspector

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THE LAGUNA DISTRICT.

In 1918 the Federal Horticultural Board deemed it advisable to establish a research station in a locality where there was a sufficient infestation of the pink bollworm to make possible the gathering of detailed information regarding this serious cotton pest. This research station was established in February, 1918, in Ciudad Lerdo, Durango, Mexico, near Torreon. Approximately 95 per cent of the upland cotton produced in the Republic of Mexico is grown in this vicinity, the so-called Laguna district.

¹ *Pectinophora gossypiella* Saunders: Order Lepidoptera, family Gelechiidae.

² This report is based on two years' work in the Laguna, conducted by the Federal Horticultural Board under authority given, in the appropriation for the eradication of the pink bollworm, to investigate in Mexico or elsewhere the pink bollworm as a basis for control measures. The experts conducting this investigation were transferred to the Board for this purpose from the Bureau of Entomology and this paper is therefore offered for publication as a joint contribution from these two offices. Provision for the establishment of the laboratory in Mexico and authority for the work was obtained through the courtesy of Senor Pastor Rouix, Secretary of Agriculture of Mexico. The work was made possible also by the active cooperation and assistance of the cotton planters of the Laguna. Special thanks are extended to the Tlahualilo Company, the Testamentaria de Carlos Gonzales, and to Mr. Lloyd Rone for the use of their plantations for experimental purposes and many other courtesies. This station was established during 1918 under the general field direction of Mr. August Busck and was continued by the authors of this paper under the general direction of the chairman of the Board and Dr. W. D. Hunter.

The Laguna district is an irregularly shaped valley of about 2,000 square miles, almost completely surrounded by mountains. It is situated about 250 miles south of the Rio Grande, on the boundary line of the States of Durango and Coahuila, Mexico. It derives its name from the fact that it was formerly a lake (laguna) serving as an outlet of the Rio Nazas. As recently as 1837 a part of the Tla-

hualilo property was under water and at present there are considerable areas near San Pedro, Coahuila, which are filled with water when the river is at a flood stage. The soil is a deep alluvial deposit, very rich, and well adapted to the culture of cotton.

CLIMATIC CONDITIONS.

Torreón, the principal city of the Laguna, has an elevation of about 4,000 feet. Generally speaking, this section of the country receives an average of 6 to 8 inches rainfall annually, but in 1919 the precipitation was very close to 15 inches.

In the months of May, June, July, and August temperatures range from 95° to 100° F. during the day

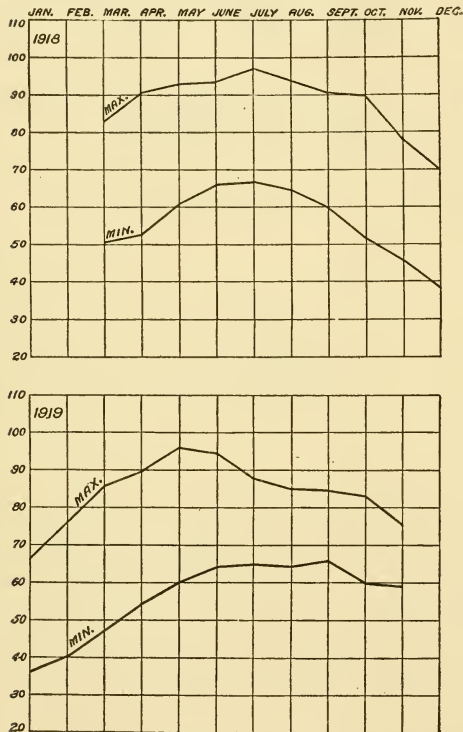


FIG. 1.—Average mean temperature for 1918 and 1919 at Ciudad Lerdo, Durango, Mexico.

down to about 64° (average) at night. In the winter months of December, January, and February the thermometer registers from 69° (average maximum) to as low as 24° F.

Figure 1 gives a graphic record of the thermometer readings taken at the station in Ciudad Lerdo, Durango.

It must be kept in mind that the above charts represent the average of the daily readings for each month and not the extremes which

were reached. The relative humidity is rather high, often reaching the saturation point at night.

From monthly records kept by the Tlahualilo Co., at Tlahualilo, Durango, covering a period of 15 years extending from 1904 to 1918, inclusive, the average rainfall for that region has been 8.07 inches per year.

TABLE I.—*Annual precipitation in inches at Tlahualilo.*

Year.	Precipitation.	Year.	Precipitation.	Year.	Precipitation.
1904.....	6.09	1909.....	13.32	1914.....	11.42
1905.....	11.31	1910.....	3.91	1915.....	4.63
1906.....	12.09	1911.....	6.98	1916.....	4.30
1907.....	8.71	1912.....	8.56	1917.....	3.46
1908.....	6.43	1913.....	12.79	1918.....	7.14

From records taken at the laboratory in Ciudad Lerdo, the following figures are given, covering the years 1918 and 1919, the years during which the observations relating to the pink bollworm in this report were made.

TABLE II.—*Monthly precipitation in inches at Ciudad Lerdo, Durango.*

Month.	Precipitation.	
	1918	1919
January.....	(¹)	1.20
February.....	(¹)	Trace
March.....	0.35	0.54
April.....	Trace.	0.00
May.....	0.02	0.00
June.....	2.76	1.44
July.....	Trace.	3.98
August.....	1.56	5.16
September.....	0.07	1.75
October.....	0.09	0.87
November.....	1.74	0.15
December.....	0.21	² 0.00
Total.....	6.80	15.09

¹ No record.

² Record only for Dec. 1-10.

CULTURAL METHODS AND PRODUCTION.

This section is semiarid and depends upon the water from the Rio Nazas and Rio Agua Naval for irrigation. The water usually comes down some time between August and December and is applied at a rate which is equivalent to about 1 meter deep to the fields that are to be planted in the following year. With an occasional rain in June or July or a small amount of water from the river during these months the fall irrigation suffices for the crop. As there is not enough water for all the land, only a small portion is cultivated, and on some plantations a portion of the land regularly lies fallow for several years at a time. Under this system of cultivation the land

has to be well prepared and thoroughly cultivated in order to conserve the moisture. The cotton planting begins about February 15 and may continue until June if there are June rains or water in the river. The land is planted as soon as possible after it dries out, as this is necessary to secure germination.

Cotton is the principal crop grown in this section, and while there are small areas devoted to corn, wheat, beans, and alfalfa, most of the planters use their land year after year for cotton and buy the feed for their domestic animals elsewhere. No very reliable data are available on acreage and production in the Laguna, but the annual production varies from 60,000 to 150,000 bales, with an average crop of from 75,000 to 80,000 bales. The yield varies from one-fourth bale to 2 bales per acre, with an average of from one-half to three-fourths of a bale. All of the cotton is of the short-stapled varieties, as it has been found by experience that these give better results than the long-staple or Egyptian varieties.

DISTRIBUTION OF THE PINK BOLLWORM.

The species is widely distributed throughout the cotton-producing world, and according to Gough (12)³ is now known to occur in India, Palestine, Mesopotamia, Ceylon, Burma, Straits Settlements, China, Japan, the Philippine and Hawaiian Islands, East Africa, Zanzibar, Egypt, Sudan, West Africa (Southern Nigeria, Sierra Leone), Brazil, Mexico, and Texas in the United States. It has more recently been found in a limited area in western Louisiana adjoining the infestation in eastern Texas.

INTRODUCTION INTO MEXICO.

The pink bollworm was introduced into Mexico in 1911. During that season two importations of Egyptian seed were made. One consisted of 125 sacks and was planted near Monterey, in the State of Nuevo Leon. The other, consisting of 6 tons, was planted near San Pedro, State of Coahuila, in the Laguna district. From what is known of the abundance of the pink bollworm in Egypt in 1911 it is probable that both shipments of seed were infested and that both of them contributed to the present infestation in Mexico. Cotton culture has not been continued in the vicinity of Monterey, but the crop of Egyptian cotton produced there in 1911 attracted considerable attention and much of the seed was shipped to the Laguna.

At the present time the pink bollworm is generally and uniformly distributed in the Laguna.

PRESENT DISTRIBUTION IN MEXICO.

Outside of the Laguna district the pink bollworm is known to be established in three localities in Mexico. One of these is at Santa

³ Italic numbers in parentheses refer to "Literature cited," p. 57.

Rosalia, State of Chihuahua, at a point about 200 miles south of El Paso. The other two infestations are located in the northern portion of the State of Coahuila. One of these is at San Carlos, at a point about 15 miles southwest of the town of Jimenez on the Rio Grande, or about 40 miles approximately west of Eagle Pass. At this place infestation has been found in fields in the immediate vicinity of the gin. None of the insects were found in outlying fields. The other infestation in the State of Coahuila is located at Allende. This is about 40 miles from the nearest point on the Rio Grande.

During the season of 1919 inspections were made by agents of the Federal Horticultural Board in the cotton region between Matamoras and Nuevo Laredo. No traces of infestation were found. Likewise the cotton growing in the Imperial Valley in the State of Lower California has been inspected with negative results. Inspection of these regions will be continued, as the insect may at any time become established along the Rio Grande by shipments of seed from the interior of Mexico.

The remarks above refer to infestations in growing cotton. The pest is frequently brought to the border towns of Mexico in cotton seed scattered in freight cars, and living specimens are constantly being found under such conditions by the inspectors of the Federal Horticultural Board.

LIFE HISTORY.

SUMMARY OF LIFE CYCLE.

The moths of the pink bollworm emerge in the early spring and summer from larvæ which have passed the winter in cotton seed or bolls. The eggs are laid soon after emergence on almost any part of the plant. The incubation period is from 3 to 12 days and the larvæ begin feeding in the squares or bolls. During the spring and summer the larval period occupies from 8 to 16 days, but in the fall and winter it is extended over a period of from a few months to two years or more. These two kinds of larvæ, while indistinguishable taxonomically, may be designated short-cycle or "summer" larvæ and long-cycle or "resting" larvæ. Pupation takes place in the soil or trash on the surface of the soil, in the summer stage, and in the ground, seed, or lint in the resting larvæ. The pupal period covers from 6 to 20 days. The average length of the life cycle from egg to egg during the summer is 31 days.

LABORATORY METHODS.

The experiments with the life history of the pink bollworm were all conducted at Ciudad Lerdo, Durango, Mexico. An adobe house was used for a laboratory. The adults were confined in 2-quart fruit jars covered with cheesecloth for oviposition. Branches of cotton plants containing leaves and squares, stuck in tubes of water

to keep them fresh, and bolls were provided for oviposition. Pieces of blotting paper dampened with water or sweetened substances were added as food for the moths. The eggs were removed to other jars for hatching and the young larvæ carefully removed to the food. Bolls and squares were used, but the squares were found more satisfactory. The food with the young larvæ was placed in vials plugged with cotton. The pieces of bolls would become discolored, decomposed, and unsuitable for food in one or two days, while a square would remain in good condition several days and the larva could be examined daily with less disturbance.

Wire cages were also used over small potted plants and cotton plants in the experimental plat to check the laboratory results. The pupæ were removed to glass vials with a piece of damp cotton in the bottom to provide the necessary humidity.

Temperature and humidity records were made with maximum and minimum thermometers and recording hygrothermographs placed indoors and outside in a U. S. Weather Bureau instrument shelter.

MOTH.

DESCRIPTION.

The moth with wings spread is about three-fifths of an inch from tip to tip, dark brown in color, with irregular blackish markings on the forewings, the hindwings silvery gray with no distinct markings. The forewings are bluntly pointed, the hindwings acutely pointed, and both heavily fringed posteriorly. When at rest the wings are folded flat over the back.

HABITS.

The moths are very seclusive in their habits during the day. It is exceptionally rare to find one in the fields until after sundown. Just at dusk they can be seen flitting very quickly from plant to plant, and by close examinations with a flashlight at night they can be readily found in a resting position on almost any part of the plant. They are active as late as 12 p. m. No observations were ever made later at night, but it is very likely that they remain active until daybreak. Occasionally they conceal themselves on the plant, but usually they crawl under trash, stones, clods, or even into the loose soil. They are very loath to leave their hiding places during the day, but when disturbed they run with a quick jerky movement or fly a short distance and immediately hide under the nearest object.

In the laboratory the moths emerging from stored cotton would congregate on the window screens at dusk. They would remain quietly till morning and then return to their hiding places. Only rarely would one be seen during the day.

LONGEVITY.

Males and females are produced in about equal proportions and their length of life is about equal. Under favorable laboratory conditions one moth was kept alive for 26 days, but the average length of life of the adult was 14.7 days. There are no indications that moths ever live for long periods of time or pass the winter in this stage.

Whether moths under natural conditions ever take nourishment other than water was never observed, but just as many eggs were deposited in the breeding jars where pure water was used as where sweetened water was substituted. Water is a very essential factor in the longevity of the adult. The average length of life of the moths where no water could be obtained was 7.6 days, compared to 14.7 days when water was supplied daily.

PREOVIPOSITION PERIOD.

Eggs were deposited in captivity from 1 to 6 days after issuance of the moth, with an average of 3.8 days preoviposition period. It is not known how long a period elapses before oviposition begins in nature, but from analogy with other species it is possible that the bulk of the eggs are laid the first night under normal field conditions. The moths were never observed in the act of depositing eggs, either in the fields or in the breeding cages, but from the night-flying habits of the moth it is evident that oviposition takes place at dusk or at night.

EGG.

DESCRIPTION.

The egg is small, elongate oval, somewhat broader at one end; length from 0.4 to 0.6 mm., breadth 0.2 to 0.3 mm.; shell iridescent, pearly white with greenish tint when first deposited, turning to almost red before hatching; surface finely reticulated with regular longitudinal lines or ridges with irregular cross-connections, resembling the reticulations on the hull of a peanut. (Fig. 2.) The larva can be easily seen inside the shell just prior to hatching.

POSITION ON PLANT.

The eggs are deposited on all parts of the plant, including the bolls and bracts, leaf buds, leaves, stems, and squares. The preference is for some more or less hidden location, such as the base of the boll, between the bracts and bolls, the folds of the small leaf buds, the creases formed by the veins and midribs of the leaves, and the axils of the leaves.

Some heavily infested plants were examined at Lerdo during August and September, 1919, to determine the proportion of eggs



FIG. 2.—Egg of *Pectinophora gossypiella*. Highly magnified.

deposited on different parts of the plants, the results of which are given in Table III.

TABLE III.—*Location on the cotton plant of the eggs of P. gossypiella.*

Number of plants examined.	Number and location of eggs.							Total number of eggs on plant.
	Leaves.	Stems.	Buds.	Squares.	Bolls.			
					Bracts.	Base.	Tip.	
1.....	7	6	45	1	8	81	0	148
1.....	32	6	107	3	11	108	3	270
1.....	21	36	34	0	74	87	0	253
1.....	94	36	66	2	54	53	1	315
1.....	31	24	37	3	78	49	1	223
1.....	20	16	56	1	93	55	2	243
1.....	22	15	17	3	2	39	0	98
Total(7 plants).	227	139	362	13	320	472	7	1,549
Percent.....	14.7	9.0	23.4	0.8	20.7	30.5	0.5	.....

It is clearly seen that the boll is the most favored place, 51.7 per cent of the entire number of eggs being deposited on the boll and its appendages. The small leaf buds were second with 23.4 per cent, the leaves third with 14.7 per cent, the stems fourth with 9 per cent, and the squares fifth with only 0.8 per cent. It is further seen from this table that the base of the boll is frequently selected, as 30.5 per cent of the eggs were deposited there and only 0.5 per cent were deposited in the sutures at the tip of the boll. The position of the eggs upon the plant is important, for upon it largely depends the fate of the young larvæ. It is essential that the larvæ reach the squares or bolls to feed, as no larvæ were ever found which had developed beyond the second instar on other parts of the plant. It is a mistaken instinct of the moths to oviposit in other parts of the plant, as it is evident that a much larger proportion of the larvæ hatching from eggs laid in close proximity to the food will reach it than of those that have to crawl over the plant exposed to their natural enemies in search of food.

When laid on the leaves, buds, stems, and squares the eggs are usually placed singly or in small groups of from 5 to 10. When laid on the tip of the boll they are placed singly or in small groups in the sutures. In this position the eggs are often flattened or crushed by the growing of the boll. When laid at the base of the boll they are placed between the calyx and the boll or beneath the bracts around the base of the boll, and are usually in masses of from a few to as many as 75 to 100, which are overlapped and flattened out more or less shingle fashion. The flattened appearance in this case is due to the presence of the calyx and not to the natural shape of the egg. In these masses, eggs of all stages of development, as well as shells, are found, showing that they were not all deposited at one time by a single female.

As the female does not deposit eggs readily in captivity, difficulty was experienced in determining exactly how many eggs were deposited by a single female. In our experiment usually from 5 to 20 moths were confined in one cage. Under these conditions it was never known which moths had oviposited and which had not, and while several hundred eggs were often obtained from a cage, it is certain that the maximum number they were capable of laying were never obtained. Often heavy, pregnant females were found dead in the cage and apparently never had deposited any eggs. Upon dissection of gravid females the ovaries were found to contain from 75 to 125 well-developed eggs. Busck (8) places the number at over a hundred and Willcocks (7) says that while small individuals may produce only about 250 eggs, well-developed individuals are capable of laying 400 to 500 eggs or more.

INCUBATION.

All of our records were made under laboratory conditions. Figure 3 shows that the difference between the maximum and the minimum, or the day and night temperatures, for each month amounts only to from 6° to 8° F.

The egg stage, even under these rather constant conditions, varied from 3 to 12 days. The range for the months of April, May, September, and October was from 7

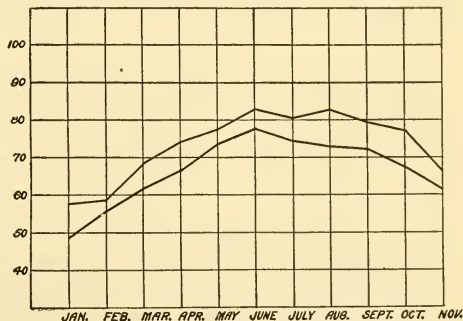


FIG. 3.—Average mean maximum and average mean minimum temperatures for 1919 at Ciudad Lerdo, Durango, Mexico.

to 12 days, and for June, July, and August it was from 3 to 5 days, with an average of 4.6 days for the entire season, the average being taken from 300 records based on thousands of eggs.

HATCHING.

The actual hatching of the egg requires only a very short time. The young larva can be seen moving inside the shell a short time before it actually emerges. An opening is cut in the broad end of the egg and the small larva wriggles out and crawls rapidly away in search of food.

The empty shell is white and soon becomes an almost unrecognizable wrinkled object. It remains on the plant until it decays or is carried away by the wind or other agencies.

LARVA.

NEWLY-HATCHED LARVÆ.

The newly-hatched larvæ are creamy white, with dark-brown head and thoracic shield and long, prominent, dark setæ showing very plainly. They are a little less than 1 mm. in length and gradually taper from the head, having thus a slight wedge-shaped appearance. In this stage the larvæ are very active. Under laboratory conditions they are very restless and crawl rapidly from place to place before entering a square or boll. Many larvæ continue crawling around for 24 hours or more until they become so weakened that they are not able to cut their way into the squares or bolls. It was often observed that most of the larvæ which succeeded in entering the food provided for them did so the day they were hatched. It is not known to what extent this wandering around takes place under natural conditions. Larvæ are found crawling over the plants, but they always seem restless and ill at ease. This probably does not take place normally to any great degree, except in the case of larvæ from eggs laid on other parts of the plant than the squares and bolls.

LARVÆ ENTERING BOLLS.

The larvæ do not seem to have any preference as to where the boll is entered. Sometimes a light netlike web is spun and the entrance is made underneath it. At other times the entrance is made with no protection whatever. The larvæ cut the carpel away, throwing the fragments outside, very little if any being consumed. The time required for the larvæ to enter may vary with the age of the boll, but it usually takes them from 20 to 40 minutes to become completely hidden. If the boll is examined soon after they have entered, the holes are easily located by the surrounding frass, and although minute, can be seen with the naked eye. After 2 or 3 days the frass is blown away by the wind or removed by other agents and the holes close up, leaving only brownish spots which are hard to differentiate from other discolorations on the boll. Then they can only be detected by a trained eye, and the only way to be certain a boll is infested is to examine its interior.

LARVÆ AFTER ENTERING BOLLS.

After the boll has been entered the larvæ become glassy white, soft, and sluggish. They so closely resemble the watery lint at this stage that they would be very easily overlooked, except for their dark heads and thoracic shields, which show as black specks against the lint.

There are three molts, completing four larval instars or stages. The first stage lasts about 2 days; the second and third, 3 to 4 days each; and the fourth, 4 to 5 days; thus the larval development is

completed in an average of 13.3 days in the summer larvæ. The second and third instars resemble the first in general appearance, and it is usually in the fourth or last larval stage that the larvæ change to the characteristic pink color from which the name "pink bollworm" is derived. Sometimes the pink color appears in the third instar, especially if development has been retarded in some way or the larva has been exposed to the air. The coloring first appears as transverse pink lines on the dorsal side of the segments and diffuses and deepens till there is only a small whitish or flesh-colored line left between the segments. The color seems to be more pronounced in the larvæ which reach maturity in the late summer or early autumn and is a very deep pink or dull red. The head and thoracic shield are reddish brown with dark-brown mandibles and anal plate. The ventral side, legs, and prolegs are white to flesh colored, the legs and prolegs with brownish claws and crotches. The full-grown larva is cylindrical and measures about one-half inch in length.

With the fourth stage the larva becomes very active again when disturbed and conceals itself as quickly as possible. A cocoon is spun attached to whatever object the larva is hiding in. The full-grown larva is never content outside a cocoon after it leaves a boll or seed. If it is taken from one cocoon it will immediately make another. How many times this will be repeated was not determined, but a perfectly healthy larva is rarely if ever found outside a cocoon, except when crawling from place to place.

PUPA.

The pupa is whitish, with faint markings of pink when first formed, turning to a mahogany brown as it dries and to a darker brown before emergence. It measures 8 to 10 mm. in length by 2.5 to 3 mm. in width. The surface is covered with a fine velvety pubescence, the posterior end terminating in a short, stout, upwardly pointing, hooklike process.

PUPATION OF SUMMER LARVÆ.

When the summer larvæ have completed their feeding, they cut to the outside of the boll directly through the carpel wall from the last seed attacked and drop to the ground for pupation.

This exit hole through the carpel wall is usually round and clean cut and can be easily recognized as having been cut from the inside of the boll. Plate II, A, gives a comparison of the entrance hole into the boll of the common bollworm, *Chloridea obsoleta* Fab., and the exit hole of the pink bollworm. The entrance holes of the common bollworm are larger, not so clean cut, and surrounded by a raised margin. They are not likely to be confused once both have been seen.

In the case of the summer larvæ, the holes made in the green cotton boll are always for the exit of the larvæ, and not for the issuance

of the moth. From an examination in 1919 of over 16,000 green bolls that averaged over 2.5 larvæ per boll, not a single pupa or pupal skin was found. Should a larva cut a hole in a green growing boll for the issuance of the moth, this hole would probably close from proliferation before the pupal stage of 9.3 days is passed.

Occasionally, in mature or dry bolls, as distinguished from green ones, more than a mere exit hole is cut when the larva reaches the carpel wall. The carpel tissues and the adjoining lint are cut away and an elongate pocketlike cavity is made large enough for the larva to become straightened out in its final preparation for pupation. When this is done a light cocoon is spun inside this cavity and a hole cut through the carpel wall to the outside. The last remaining parts of the carpel wall are not cut entirely out leaving an open hole, but the particles are held together and in place by a few fine strands of silk which are easily broken and pushed away when the moth emerges.

The very fact that only a few larvæ pupate in the bolls is conclusive enough that there are other more favorable places for pupation. These places are either on the ground or in the ground. If the moisture conditions are sufficient on the surface, they may spin a cocoon in the trash or on any convenient object, and pupate there; but if it is too dry and the soil is loose they may burrow as deep as 3 inches below the surface, make an earthen cell, line it with a very fine, tough cocoon, and pupate there. During the summer a good many pupæ are probably destroyed by cultivation, but when pupation takes place in the ground, only the exit passage being destroyed and the pupa itself not molested, the moth may be able to escape because of its burrowing power.

Fullaway (3) and Busck (8) found that in Hawaii pupation normally takes place in the boll and only rarely in the soil or other places. Maxwell-Lefroy (2) found that in India pupation occurs in the boll or on the bracts or leaves of the cotton, and in unirrigated black cotton soil might be found in a crack of the dry soil. Willcocks (7, *p.* 113) says that in Egypt—

Pupation seems most often to take place on the ground under the fallen leaves, or in the fold of a dead leaf or again between two dead leaves, also on old bolls which have dropped or been broken off, and under or attached to small lumps of earth. In fact they may be looked for amongst any shelter of this kind. One situation was noted that seems to be especially favored by the larvæ as a haven to pass the pupal stage, this was furnished by the dead flowers which are of course very numerous below the plants.

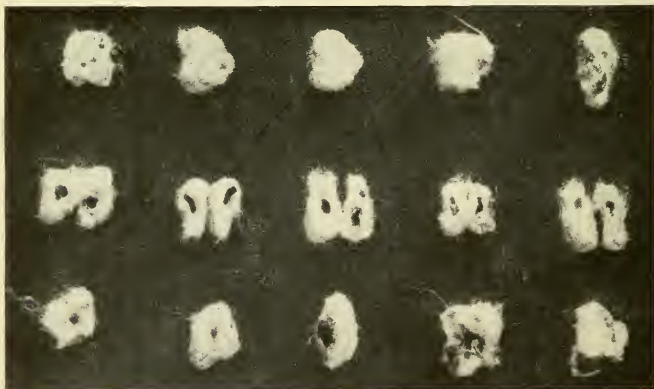
In Mexico pupæ were never found on the leaves or bracts under field conditions. When green bolls were picked and left in sacks the emerging larvæ would sometimes hollow out a slight depression and pupate near the base of the boll, or they would pupate between the involucre and boll without making a depression, or spin their cocoons



COTTON BOLLS SHOWING CHARACTERISTIC INJURY BY THE PINK BOLLWORM.



A, On left, entrance hole of *Chloridea obsoleta*. On right, exit holes of pink bollworm. (Hunter.)



B, Double seed formed by pink bollworm larvae; Above, holes made for issuance of moth; middle, broken apart to show cavities; below, double seed intact.

PINK BOLLWORM.

on the sides of the sack. The old flowers under the plants did not seem to be more favored than other bits of rubbish.

The duration of the pupal stage of summer larvæ from 150 records ranges from 6 to 14 days. There is considerable variation among the individual pupæ, some requiring 1 to 2 days more than others which pupated on the same night.

Table IV summarizes over 300 complete records of the various stages of the pink bollworm at Lerdo, Durango, Mexico, during 1918 and 1919.

TABLE IV.—*Duration in days of summer stages of P. gossypiella.*

	Average
Egg stage.....	4.6
Larval instars:	
First.....	2-3
Second.....	3-4
Third.....	3-4
Fourth.....	4-5
Total average.....	13.3
Pupal stage.....	9.3
Preoviposition period.....	3.8
Total period from egg to egg.....	31.0

RESTING LARVÆ.

In the preceding part the development of the different summer stages of the pink bollworm has been discussed. There is still another important phase of the life history—the long-cycle or resting larvæ. It is in this stage that the species passes the winter when no food is available or when conditions are adverse in any way. It is also in this stage that the greatest dispersal by man takes place and only in this stage that any known control measures can be used.

Beginning some time in August, when the temperature is still high and there is yet plenty of food available, some of the larvæ upon reaching maturity do not pupate at once, but remain wherever they are as full-fed larvæ. These larvæ are identical in form with those that pupate and can not be distinguished from them. What causes some larvæ to do this and others to pupate as usual when reared under the same conditions is not known, but Willcocks (?) suggests it is probably some instinct inherited from the time when in its original natural habitat there were no food plants available to sustain the species over a long period of time. In November and December, when the temperature is lower and no food is available, all of the larvæ develop this tendency and it is the exception rather than the rule for them to pupate. Thus in the Laguna this resting habit seems to be a combination of estivation and hibernation, for it begins while food is still available and the temperature high. In this section the average frost date is about November 20, and moths emerg-

ing after this date would as a rule find no suitable places for oviposition.

When a larva prepares to go into the resting stage it remains in the boll in which it has been feeding. Usually a tough, heavy cocoon is spun either in the lint, in a single seed, or two seeds are fastened together to form a "double seed." (Pl. II, B.) The double seed is formed by eating away part or all of the contents of the two adjoining seeds and spinning a strong continuous cocoon inside the cavities of the two seeds, which holds them firmly together and makes them difficult to separate.

Part of these seeds go through the gin and come out intact, and finding double seed is sure evidence of pink-bollworm infestation.

Often double seeds are formed in seed in different locks, the connecting cocoon running through the hole made in the partition wall. This affords good protection for the larva, as it prevents the seed from falling to the ground and being exposed to excessive moisture and other agencies which are more detrimental to the larva on the ground than on the plants.

When the cocoon is spun in the lint or a single seed the larva lies in a curled-up position and the cocoon is spun tightly around it, forming a spherical compact mass. Similar cocoons are formed in the ground or attached to any convenient object if larvæ are removed from seed or lint. The cocoon fits so closely and is so tough that it is very difficult to remove without injuring the larva. It is very hard to detect a larva inside a seed, and the only sure way to tell whether the seed contains a larva is to examine the interior. Willcocks (?) in writing about Egyptian cotton seed, which has a smooth, black coat and is not covered with lint, says the silken-covered entrance hole can usually be seen with a lens. This, however, does not hold true for short-staple seed.

Few data are available on the number and proportion of larvæ found in the lint and in the single and double seed. Samples of cotton were hand-ginned and the number of larvæ in single and double seed determined, but unfortunately no record was kept of the number in the lint. It is possible that some of the larvæ counted as in single seeds in the first and second picking samples were in the lint, but this did not occur in the samples of the third picking. It will be noted that the sample for the third picking is from the 1918 crop and had been stored for some time. At the time of examination a considerable part of the larvæ were dead, but this does not affect the proportion found in the single and double seed, and while the figures are not quite comparable, they at least give an idea of the number of larvæ present at different times. The number of larvæ found in the single and double seed for the different picks are given in Table V.

TABLE V.—*Number of pink bollworm larvæ found in single and double seed of cotton picked at different dates.*

Weight of sample.	Date picked.	Date examined.	Double seed.			Single seed.		
			Number double seed.	Number of larvæ in double seed.	Per cent of total larvæ in double seed.	Number single seed damaged.	Number of larvæ in single seed.	Per cent of total larvæ in single seed.
First picking:	1919.	1919.						
½ pound.....	Aug. 4	Oct. 10	0	0	0	38	2	100
1 pound.....	Aug. 6	Oct. 8	10	0	0	108	1	100
1 pound.....	Sept. 23	Oct. 22	0	0	0	156	3	100
Second picking:								
½ pound.....	Oct. 16	Oct. —	30	29	58	121	21	41
1 pound.....	Nov. 2	Oct. —	34	30	56.6	467	23	43.4
Third picking:	1918.							
½ pound.....	Dec. 3	Mar. 30	106	95	30	715	250	70
1 pound.....	Dec. 10	Mar. 20	36	26	33	597	53	67

¹ One pupa in lint, not counted in above.² Two pupæ in lint, not counted in above.

This table shows that no double seed was found in cotton from the first picking, that 57.3 per cent of the larvæ were found in double seed from the second picking, and that the percentage fell to 31.5 in the third picking. It is probable, however, that occasional double seeds are formed during August and September or in the first picking.

Taking an average of these figures and reducing them to a 1-pound basis, the number of larvæ per bale present in the seed from the different pickings can be calculated. It is thought that no live larvæ pass through the gins in the lint, and that many of the larvæ in the seed are driven out during the cleaning and ginning. It is certain that the large number found in seed when hand-ginned were never found in commercially ginned seed.

TABLE VI.—*Number of pink bollworm larvæ found per pound and the estimated number per bale in cotton from different pickings.*

Weight of sample.	Double seed.				Single seed.				
	Number double seed.	Number larvæ in double seed.	Estimated number of larvæ per bale in double seed.	Per cent of total larvæ in double seed.	Number single seed damaged.	Number larvæ in single seed.	Estimated number of larvæ per bale in single seed.	Per cent of total larvæ in single seed.	Estimated number of larvæ per bale in single and double seed.
First picking:									
1 pound.....	0	0	0	0	121	6	9,000	100	9,000
Second picking:									
1 pound.....	43	39	58,500	56.5	392	30	45,000	43.5	103,500
Third picking:									
1 pound.....	189	161	241,500	28.5	1,749	404	606,000	71.5	847,500

Gough (5), in one of his earlier publications, states that there are two generations of the hibernating larvæ, the older generation con-

sisting of full-fed worms and the younger the winter-feeding brood, which were not full-fed at the time of hibernation and continue developing slowly till about March. In a later publication (12) weighings of resting larvæ were made from January to July and it was found that the weight constantly fell from February to July. He concludes that "the fall in weight does not necessarily demand the explanation that the larvæ were fasting, but taken along with the known fact that many hibernating or æstivating larvæ do not feed, it lends considerable weight to the probability of the larvæ not feeding during their resting period."

A very small proportion of the larvæ have not completed their growth when the cotton is picked, and these continue feeding for a while before making their resting cocoon. In some bolls examined November 26, 1918, there was an average of 6.64 fourth-instars and 0.03 third-instars per boll. After the resting cocoon is once spun no feeding takes place. If larvæ are removed from the seeds in which they are resting, other seed will sometimes be hollowed out, but the contents are thrown to the outside and no actual feeding takes place. It sometimes happens that frost does not come in the Laguna till January or February, and it is probable that feeding continues longer than usual in such years.

DURATION OF THE RESTING STAGE.

Larvæ are capable of passing long periods of time in this quiescent stage. Gough (5) found in seeds of Indian cotton which had been imported to Egypt larvæ which were over 2 years old. Busck (8) in Hawaii compressed cotton seed into small bales and found live larvæ in them for 18 months. Willcocks (7) stored a large number of bolls picked in November, 1913, in an outdoor cage, and moths continued emerging till August 28, 1915, a period of nearly 2 years. There were 4.4 per cent of the larvæ in double seed collected in November, 1918, still alive on November 20, 1919, when work at the station was discontinued.

PUPATION OF RESTING LARVÆ.

When the resting stage has been passed in the lint, single seed, or in any place where the larva is curled up in a small, compact cocoon, it is necessary to leave this cocoon and prepare more ample quarters for pupation. In such cases a lighter, more elongate cocoon is usually spun among the fiber or seed, but in some instances in stored seed pupæ are formed without any protection whatever.

When the resting stage has been passed in the double seed the construction of the cocoon between the two seeds makes it elongate enough for the larva to pupate successfully and pupation usually takes place *in situ*. In such cases the emergence hole for the moth

is cut just prior to pupation and not when the seeds are first webbed together. Often the end of the pupal shell is seen protruding from the seeds through this opening.

When pupation occurs in old bolls of cotton a favorite method is to make a slight depression in the lint and pupate between the cotton and boll. Where hibernation has been in the fields larvæ may leave the bolls and pupate in the ground. On March 14, 1919, 1½ square yards of soil in the corral at Lerdo, where many bolls were lying around, were examined. Four live larvæ and one dead one, together with one live pupa and several empty pupal cases, were found. All were near the surface, one larva being under a piece of trash and the others an inch or so down. All the larvæ and the live pupa had light cocoons and seemed to have gone into the soil for pupation rather than hibernation. In the case of the old pupal skins it could not be determined whether they came from hibernating larvæ or were left over from the previous summer.

The duration of the pupal stage from 250 resting larvæ ranged from 8 to 26 days, with an average of 10.3 days. This is an average of 1 day more than for the summer larvæ, due to the fact that pupation took place during the colder months. There is considerable individual variation in the length of pupæ formed at the same time, but this occurs in pupæ from summer larvæ as well as from resting larvæ. The pupæ from which male moths emerged required an average of one-half day more than those from which females emerged, the males requiring 10.5 days and the females 10 days.

TIME OF EMERGENCE FROM RESTING LARVÆ.

A few moths may emerge throughout the year in the Laguna. When work was first begun in the early part of February, 1918, freshly formed pupæ were found among seed at the seed warehouses. During the month of March, 1918, there emerged 23.5 per cent of all the moths which emerged during the year from larvæ collected in seed in February and removed to the laboratory. Emergence continued till August, when all of the larvæ had died or emerged, the maximum being reached in May. Pupæ were formed from larvæ collected in the summer and fall of 1918 throughout the fall and into January, 1919, thus completing the cycle of pupation for every month in the year. The pupal period is greatly retarded during the cold months, but this does not prevent emergence on warm days. Table VII shows the monthly emergence of moths from resting larvæ for 1918 and 1919.

TABLE VII.—*The monthly emergence of moths from resting larvæ for 1918 and 1919.*

Months.	1918		1919	
	Number of moths emerged.	Per cent of total emergence.	Number of moths emerged.	Per cent of total emergence during period covered.
March.....	381	23.5	1	(1)
April.....	236	14.6	125	2.1
May.....	525	32.5	851	14.3
June.....	355	21.9	1,811	30.6
July.....	105	6.5	2,302	38.8
August.....	16	1.0	708	12.0
September.....			84	1.4
October.....			40	.7
November.....			8	.1
Total.....	1,618	100.0	5,930	100.0

¹ No complete record.

Moths emerging in 1918 were from larvæ collected in seed in February, 1918; those emerging in 1919 were from larvæ collected in bolls during November, 1918. Complete records are not available for December, 1918, or January, February, and March, 1919, due to absence from the laboratory. The percentages of moths emerging each month are based on the total number of moths which emerged and not upon the total number of larvæ. Of the larvæ collected in November, 1918, 4.4 per cent were still alive and had not pupated on November 20, 1919, when the records were discontinued.

A study of Table VII shows that emergence took place much earlier in 1918 than in 1919. During March, 1918, 23.5 per cent of the moths emerged and the maximum of 32.5 per cent was reached in May, while in 1919 only 2.1 per cent emerged in April and the maximum of 38.8 per cent was not reached till July. This seasonal variation depends largely upon the temperature and humidity. The winter of 1917-18 was unusually mild and there was an exceptionally hot period during the first week of March which hastened pupation. It was also found that dampening the seed or lint hastened emergence and a rain followed by warm weather in March or April would no doubt cause large numbers to emerge. As a rule, moths emerging before the first of May would find no suitable places for oviposition and would not be a factor in starting the infestation in the following crop.

ISSUANCE OF MOTH.

The issuance of the moth from the pupal skin requires a very short time. The pupal skin breaks or splits along the dorsal side and the moth works its way out and crawls upon some object in the open so that the wings may develop normally. As soon as the wings have extended to their full length they are raised and held in a vertical position from 5 to 15 minutes to become perfectly

dried. Afterward the moth crawls off and hides until dark, if issuance has taken place during the day. What course is followed when issuance takes place at night was never observed.

TIME OF DAY MOTHS EMERGE.

The moths emerge from the pupæ at all hours of the day and night under laboratory conditions, where the temperature and humidity are more or less uniform. From Table VIII it can be seen that between the morning examinations and the afternoon examinations, 421 moths emerged in 134.5 hours, an average of 3.1 moths per hour, and that 348 moths emerged between the afternoon examinations and the morning examinations in 301 hours with an average of 1.1 moths per hour. About three times as many moths emerged during the day as emerged per hour during the night.

TABLE VIII.—*Time of day of emergence of the adult P. gossypiella.*

Morning examination.		Afternoon examination.		Date.	Morning examination.		Afternoon examination.	
Time.	Number of adults.	Time.	Number of adults.		Time.	Number of adults.	Time.	Number of adults.
1919.				1919.				
May 22	10.00	(1)	5.25	27	June 4	10.00	(1)	5.30
May 23	9.30	16	5.30	5	June 5	10.00	22	6.00
May 24	9.30	2	5.30	17	June 6	10.00	25	6.00
May 25	10.30	15	5.30	25	June 7	10.00	14	(2)
May 26	9.30	10	5.00	27	June 8	10.00	(1)	(2)
May 27	9.30	15	5.30	26	June 9	10.00	(1)	6.00
May 28	9.30	17	6.00	13	June 10	10.00	20	5.00
May 29	9.30	13	8.30	19	June 11	10.00	26	5.00
May 30	9.30	11	6.30	25	June 12	10.00	41	5.30
May 31	10.00	46	8.30	16	June 13	9.30	8	(2)
June 1	10.00	20	6.00	15				
June 2	9.30	14	5.30	42	Total		348	
June 3	10.00	13	(2)	(2)				421

¹ All removed.

² No record.

SEASONAL HISTORY.

The data show that moths may emerge at any time during the winter or early spring, and so far as known they may begin breeding if suitable food plants are found. Cotton does not grow as a perennial in this section. Sometimes it is left for the second year to produce a "zoca" crop, but the plants are dormant during the winter and the crop is produced from sprouts sent out from the roots or old stalks. Planting may begin during the first part of February, but usually begins about the middle, depending upon the season. Squares are not formed in any numbers until about the first of May, usually a little earlier on the zoca than on the plant cotton. Hollyhock, another host plant of pink bollworms, may be in bloom earlier than cotton, but it is considered of no economic importance in this connection. Repeated attempts to secure oviposition on young

cotton plants during March and April, 1918, were unsuccessful. The first eggs were laid in the breeding jars on May 5, and the first larva (one of the third instar) was found in cotton in the field on May 15, 1918. The first eggs were deposited on April 9, 1919, and the first larva found in the field on April 28. The general infestation in the fields, however, did not begin till later in 1919 than in 1918.

In general, it may be said that breeding commences in the spring as soon as the squares begin to mature and by the time the first blossoms appear a few larvæ are present. The infestation is extremely light at this season and only by careful search will any larvæ be found. As a rule the bolls are not attacked till they are from one-half to three-fourths grown, though occasionally a larva works down from the blossom to the newly set boll. It is usually about the middle to latter part of July before bolls on plant cotton are sufficiently mature to be attractive to the larvæ. From this date onward the infestation rapidly increases, and in about 10 weeks' time practically every green boll is infested. The cool nights of October and November check the development somewhat, but breeding continues until frost destroys the food plants.

Table IX shows the weekly increase in the percentage of green bolls infested during the 10 weeks during which breeding is most active. It is computed from weekly examinations of samples of green bolls collected on different plantations, an average number of 350 in 1918 and 1,100 in 1919 being used.

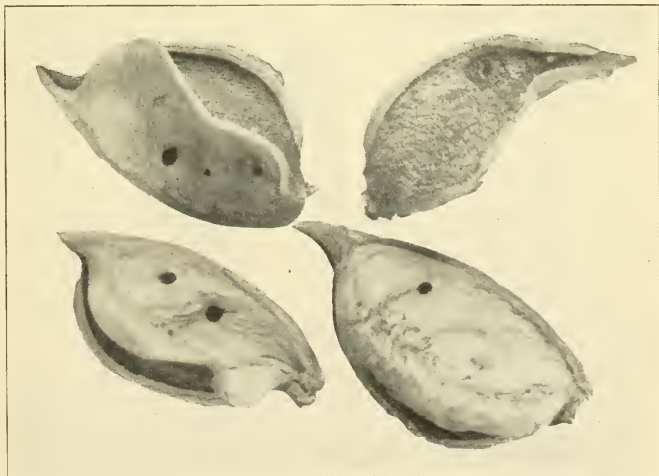
TABLE IX.—*The weekly increase in the percentage of green bolls infested with Pectinophora gossypiella.*

Week ending—	Percentage of green bolls infested.		Week ending—	Percentage of green bolls infested.	
	1918.	1919.		1918.	1919.
July 12.....	1.1	.....	Aug. 30.....	79.2	20.8
July 19.....	7.0	.....	Sept. 6.....	93.0	29.0
July 26.....	13.6	.....	Sept. 13.....	97.3	41.0
Aug. 2.....	20.0	.....	Sept. 20.....	.....	45.0
Aug. 9.....	21.0	4.3	Sept. 27.....	.....	63.0
Aug. 16.....	42.0	5.0	Oct. 4.....	.....	83.3
Aug. 23.....	65.8	10.8	Oct. 11.....	.....	100.0

From Table IX it is seen that the time of active breeding varies considerably, and that in 1919 it was a month later than in 1918. This depends largely upon the development of the cotton. The same climatic conditions which retard the growth of the cotton also affect the activity of the species, and the relative development of the two is about the same from year to year. It is also clearly shown that there are no distinct broods or generations and that the heavy infestation in the fall is accumulative. If the offspring from moths emerging early in the spring continue breeding throughout the



A, Characteristic rosette appearance of cotton flowers infested with the pink bollworm.



B, Holes cut through partition wall when larva goes from one lock to another. (Hunter.)

PINK BOLLWORM.

season till December and make a complete life cycle every 31 days, there are six generations, but if the moths do not emerge from the resting larvæ until the fall and the first generation goes into the resting stage again, the whole year may be passed in only one generation.

FEEDING HABITS OF LARVÆ.

LARVÆ FEEDING ON LEAVES AND STEMS.

The feeding of the pink bollworm on the leaves of cotton is of no economic importance. It is a forced condition rather than a voluntary one. If the eggs have been deposited a long way from the squares or bolls, the larvæ may feed slightly on the leaves while searching for suitable food. In such cases slight abrasions on the surface of the leaf or minute pinholes through the leaf occur. The larvæ feeding in this manner appear either to die for lack of sufficient nourishment or to be destroyed by other insects. No larvæ older than those of the second instar were ever observed feeding on leaves and only two or three cases of the second instar. No indications of entrance into the bolls by larvæ of the second or later stages were ever observed under field conditions, except where the larvæ had been feeding in blossoms and had worked downward into the newly set bolls. Willcocks (?) records larvæ feeding in the stems of the plants just above the surface of the ground in Egypt, but this class of injury was never seen in the Laguna.

LARVÆ FEEDING IN SQUARES AND FLOWERS.

The young larvæ enter the squares by cutting directly through the undeveloped flower petals and feed on the pollen and fleshy parts of the embryonic flower, usually reaching the third or fourth instar by the time the flower opens. These infested flowers do not open normally, but have a peculiar rosette appearance which is well shown in Plate III, A. The tips of the corolla in infested flowers are webbed together by the larvæ with fine silken threads which prevent their opening wide and exposing the larvæ to the attacks of other insects and the heat of the sun.

These infested flowers are easily distinguishable from normal flowers in walking through fields of upland or short-staple varieties. Even though the percentage of infested flowers was about the same in Egyptian or long-staple cotton the pronounced rosette effect was never seen. The corolla is longer and larger in Egyptian varieties and the threads spun by the larva probably are not sufficiently strong to prevent its opening. When infested flowers are examined the larva is usually found beneath a fine silky web, covered with frass and pollen grains, and feeding upon the anthers. If full-fed when the flower opens it may leave it the first day and drop to the ground for pupation. This is especially apt to occur if the larva is dis-

turbed by other insects, such as the flower beetle, *Euphoria basalis* Gorg. If the larva is not full-fed at the time of opening it may continue feeding inside the flower for two or three days or until after the flower has dropped, or it may work downward from the flower into the newly formed boll. No indication of the larva leaving flowers and going into large bolls was ever observed, and it is exceptionally rare to find more than one larva in a single square or flower. From June 1 till August 10, 1919, a daily record, with a few exceptions, was kept of the flowers opening on a small plot of heavily infested cotton at Ciudad Lerdo. The results are given in Table X.

TABLE X.—*Infestation of cotton blossoms by the pink bollworm.*

Month.	Number of days counted.	Infested.	Non- infested.	Total.	Percent- age infested.
June.....	25	226	8,210	8,436	2.7
July.....	25	898	12,333	13,231	6.8
August.....	10	967	2,508	3,475	27.8

On October 3, 50 per cent and on November 10, 90 per cent of the flowers on this same plot were infested. This plot was more heavily infested than is normally the case under field conditions. The infestation is usually highest in June and July, when few large bolls are present on the plants, and decreases during August and September. In October and November, when there are many larvæ present and not so many green bolls, the infestation again increases and the few blossoms appearing at this time are heavily infested. As the feeding in the squares and blossoms is largely on the pollen, the presence of a larva does not necessarily prevent a normal boll from forming. Blossoms were tagged in 1919 and it was found that 40.8 per cent of the noninfested squares and 67.6 per cent of the infested blossoms were shed.

LARVÆ FEEDING IN BOLLS.

That inside the bolls is the most favored feeding place for pink bollworms is shown by the fact that as soon as the bolls are large enough most of the larvæ choose bolls instead of squares or flowers. They attack the boll in all stages of its growth, from the time it is the size of a pea until it begins to open, though most commonly it is not entered until about one-half to three-fourths grown. The larvæ bore into the boll at any point upon its surface soon after hatching and remain in the same boll until ready for pupation. Once the larvæ have entered the boll no definite plan of procedure is followed. They may burrow directly through the carpel and begin feeding on the soft watery lint or they may stop before cutting completely through and burrow for an inch or more in the spongy

carpel tissues just beneath the inner wall of the boll. In the latter case they leave brownish, discolored tunnels or burrows resembling the work of young leaf miners. These tunnels, commonly called "railroads," are very characteristic of pink bollworms and when found are sure evidence that a boll is infested. They disappear as the boll grows older and are not noticeable in an open boll.

When the larvæ cut directly through and into the lint sometimes a slightly discolored proliferation resembling a puncture made by a cotton stainer is formed and at other times only a slight discoloration is left. Again, a larva may be found inside a boll and no sign of its entrance place found even when the boll is examined from the inside. The larvæ may tunnel in the carpel tissues or feed in the lint in any direction from the point of entrance and seldom if ever feed on seed until after the first molt. They may burrow between or cut through the fibers of the lint for a considerable distance while feeding on the soft tissues, leaving behind slightly discolored trails through the lint and "railroads" through the immature seed coats; or, on the other hand, they may remain feeding on the lint near the point of entrance.

Second or third instar larvæ are found which seem to have fed exclusively on the lint, but there is always some feeding on the seed before the larvæ become fully mature and second and third instars are frequently found in the seed. The seeds are normally first attacked from the broad end nearer the outer surface of the boll. The contents of the first seed attacked are not eaten completely out before an adjoining seed is attacked. The number of seeds attacked by a single larva varies greatly, due to the age and development of the boll at the time of attack and the behavior of the larva. Cases have been seen where a larva completed its development on as few as two seeds and within a short distance of the place of entrance, while another larva may destroy a whole lock or more. Often a larva will cut through the partition into the adjoining lock instead of going to another seed in the same lock. The hole in the partition is clean cut, round or oval, and is good evidence that a pink bollworm has been in that boll. Plate III, B shows these holes.

When very small bolls are attacked by larvæ working downward from the flowers, they turn brown and usually drop from the plants, but if the bolls are not attacked till about half grown, the presence of larvæ does not cause them to shed. When there are only 2 to 4 larvæ in a boll that is rather far advanced, say three-fourths to full-grown, when attacked, the work may be classed as "clean," but if several larvæ have attacked a boll that has not reached that stage, the entire contents are very likely to be completely broken down into a decayed mass. The presence of larvæ in bolls does not prevent other larvæ from entering, and usually larvæ of all stages are found

in the same boll. During the latter part of the season, when the infestation is heavy, an average of 6 or 7 larvæ is found per boll and individual bolls may contain many more. One boll was examined that contained 26 larvæ. The number for all bolls examined throughout the season of 1919 averaged 2.5.

PROLIFERATION OF BOLLS.

The presence of larvæ often causes the bolls to form abnormal growth or proliferation. Proliferation is described by Dr. W. E. Hinds (1) as:

The development of numerous elementary cells from parts of the bud or boll which are themselves normally the ultimate product of combinations of much more highly specialized cells. The resulting product is thus composed of comparatively large, thin-walled cells, which are placed so loosely together that the resulting formation is of a soft texture, and has a granular appearance which may be plainly seen with the unaided eye.

Greenish white or discolored brownish opaque swellings are formed on the inner wall of the carpel, the seeds themselves proliferate, and very little if any lint is formed on them. This spongy mass of granular cells develops much more rapidly than lint, thus occupying the space that would have been filled with lint. Badly proliferated bolls contain but little lint, and this is matted or felted and of poor quality, thus greatly increasing the damage done by the pink bollworms. Proliferous seeds are not confined to those actually attacked by the larvæ. The irritation caused by the presence of the larvæ in a boll or the stimulation from proliferation in seed actually injured causes other healthy seed to proliferate. The percentage of proliferous bolls increases very rapidly with the advance of the season, which is simultaneous with the increase of the number of bolls attacked by the pink bollworm and with the number of larvæ in each boll. The Egyptian cotton grown at the laboratory was much more severely affected by proliferation than were the short-staple varieties. Larvæ occasionally are killed by proliferation, but from general observations it is thought that not more than one-tenth of 1 per cent are killed in this way. The result is by far more detrimental than beneficial.

DAMAGE CAUSED BY THE PINK BOLLWORM.

The damage by the pink bollworm is caused by the feeding of the larvæ on the squares and blooms, the walls and partitions of the bolls, and the lint and seed of the cotton. Upon entering the boll after hatching the larvæ feed on the lint and tender tissues of the boll during its earlier stages of growth; in the latter stages the larvæ feed almost exclusively on the seed, thereby arresting the development of the lint and seed and also destroying the seed itself. In passing from seed to seed and from lock to lock the larvæ cut and

discolor the lint. Just as soon as the bolls are formed they may be attacked by the larvæ working downward from the flower, but usually they are not attacked till one-half to three-fourths grown. The damage to the individual boll is greater the earlier it is attacked. In case the larva enters when the boll is very young, that is, one-half grown or less, the boll is usually completely destroyed. But when a boll is not attacked until it is about half grown an infestation by a larva or even several larvæ does not necessarily prevent the boll from opening and producing some pickable cotton. The cotton from infested bolls is of an inferior grade, the lint usually being short, hard, and kinky. The portion of the boll actually consumed by the larva may be comparatively small, but the damage caused by the feeding habits and presence of larvæ in a boll amounts to a considerable percentage loss to the crop. The irritation produced by the presence of a larva often causes proliferation to take place; and upon entering and leaving the boll the larvæ provide a means for the entrance of air and water, thereby causing decomposition in the green bolls.

RELATION OF AMOUNT OF DAMAGE TO INCREASE OF INFESTATION.

It has been estimated that the natural winter mortality of all insects is about 95 per cent or more. In addition to this, the number of pink bollworms in the cotton fields of the Laguna district is further reduced by the irrigation methods, fall burning of plants, and the grazing of the fields by cattle, goats, etc. It is obvious that at the beginning of the crop the infestation, even where it was general the previous year, would be very light, but as the number of larvæ in the field increases the amount of damage becomes greater.

The pink bollworm attack is not similar to that of other insects like the cotton leafworm, *Alabama argillacea* Hübn., or bollworm, *Chloridea obsoleta* Fab., which practically ruin a crop overnight, but is more of a gradual, built-up attack, starting in the beginning of the crop with practically a negligible infestation and culminating with 100 per cent of the bolls infested with from 4 to 10 larvæ in every boll. Table XI shows the rate of monthly increase of larvæ in several average fields of the Laguna.

TABLE XI.—*Progress of infestation by larvæ of the pink bollworm; number of larvæ per 100 bolls.*

Month.	Plantation.							Average.
	Hormiguero.	Alvia.	LaConcha.	San Isidra.	Zaragosa.	Rosas.	Barcelona.	
August.....	2.6	15.3	5.0	5.2	32.6	33.6	17.6	15.9
September.....	103.0	128.7	93.5	62.7	312.0	210.7	188.0	156.0
October.....	710.0	694.0	585.2	748.0	773.0	807.4	496.6	662.9
November.....	120.0	790.0	668.0	638.0	.....	864.0	464.0	724.0

The data in the foregoing table were compiled from records kept of weekly examinations made of 100 boll (green) samples taken from different plantations in the Laguna district. The bolls in each sample were taken by walking through the same fields each week and picking the bolls at random.

ESTIMATE OF DAMAGE TO LAGUNA CROP, 1919.

In making an estimate of the damage caused by *P. gossypiella* to the cotton crop of the Laguna for 1919, it was thought best to select certain average fields on average plantations and to keep these particular fields under close surveillance during the entire year.

Through the courtesy of Don Carlos Gonzales y Fariño, of Torreon and of the Tlahualilo Company, Tlahualilo, Durango, certain fields upon their properties were selected. These fields were chosen with the utmost care in order to obtain as nearly as possible an average of all conditions of the Laguna, with respect to factors controlling the amount of damage caused by *P. gossypiella*. Other fields in different parts of the Laguna were examined as often as time would permit for comparison with these fields. Each of these fields was visited regularly (as far as conditions would permit) once a week, and samples of 100 green bolls taken, so that the rate of increase of infestation might be ascertained.

Samples of seed cotton were also taken at the beginning of each pick from each of the experimental fields, to determine the damage caused by the pink bollworm in the different harvesting periods. These samples were ginned in a sample gin separately, accurate weights being kept of the quantity of lint and seed. A sample of lint from each field sample was taken for classification by the Bureau of Markets, United States Department of Agriculture, to determine the discolorations, grades, and spinning qualities of the lint.

A 2-pound sample of seed was taken from each field sample for chemical analysis to determine quality and quantity of oil.

DAMAGE TO SQUARES AND BLOOMS.

The pink bollworms enter the squares just after hatching from the eggs, and continue feeding until they complete the larval stage, notwithstanding the fact that the squares may bloom in the meantime. Larvæ of all stages have been found in the squares, but generally speaking only full-grown larvæ have been observed in the blooms. To ascertain to what extent this floral feeding habit tended to cause damage the following experiment was carried on.

Tags were placed on 343 normal blooms and on 343 infested blooms during June and July. Table XII shows the results.

TABLE XII.—*Results of experiment to determine damage caused by feeding of the pink bollworm in the blooms of cotton.*

Blooms.	Number of tags.	Dropped off.	Set bolls.	Per cent of blooms dropped.
Normal.....	343	140	203	40.8
Infested.....	343	232	111	67.6

From the above table it will be seen that 40.8 per cent of the *normal blooms* did not set bolls, but 67.6 per cent of the *infested blooms* did not set bolls, a difference of 26.8 per cent. Granting that under favorable conditions the natural tendency of the plant will be to reset these fruits, it is obvious that 26.8 per cent of the blooms will make bolls at a much later date than they normally would, thereby subjecting them to a far heavier infestation, hence a greater amount of damage. The later maturity of the crop due to shedding of the early squares would also greatly increase the damage by the boll weevil in countries where this insect is present. (See Table XI on "Progress of infestation.")

The rate of monthly increase of the infested blooms in a given field is shown in Table X.

DAMAGE TO BOLLS.

In estimating the damage caused to the mature bolls (Pl. I), pickable as well as nonpickable cotton must be considered. By pickable cotton is meant cotton that is picked, ginned, and marketed from the beginning to the end of the crop; by nonpickable cotton, the bolls or portions of bolls that are left on the plants as unfit for picking, due to damage by the pink bollworm.

PICKABLE COTTON.

To arrive at a conclusion as to the extent the cotton taken from the fields is damaged, a 100-pound sample of seed cotton was taken from each picking in each experimental field. These samples were taken by picking all the open cotton on about every twentieth plant in each row, in this manner obtaining as nearly as possible a composite average sample of the cotton open in the field on that date. After the sample was taken the remaining open cotton was picked in the customary manner, thereby guarding against the possibility of mixing any of the first and second pick cotton in the taking of the later samples.

The samples were stored until the end of the season and then ginned separately, using a small 10-saw sample gin. A gin sample of approximately 2 pounds of lint and a sample of seed weighing about 2 pounds were taken from each of the field samples at the time of ginning.

LOSS IN THE QUALITY OF LINT.

The 2-pound gin samples were sent to the United States Bureau of Markets for examination. Mr. George Livingston, Chief of Bureau, reported in letter dated April 13, 1920, as follows:

In a general way it may be stated that all of the samples were of very poor quality, especially as regards length and strength of staple. The results obtained through the ordinary commercial classification of cotton were confirmed by individual fiber strength tests which produced subnormal results. It is commonly considered that upland cotton should show an average strength for individual fibers of about 8 grams, but none of the Mexican samples possessed that degree of strength. Several of the samples were so weak that a considerable portion of the fibers broke upon being inserted in the jaws of the testing machine. Such cotton is so weak in staple as to be practically unspinnable.

The exact degree of the deterioration in the quality of lint mentioned above which is due to the pink bollworm can not be definitely stated, but undoubtedly a certain percentage of it is caused by malnutrition of the seed, which arrests the development of the lint. Ballou (11, p. 265) states:

In addition to the actual damage done to the lint and seed of the attacked seed, there is the injury which results to sound seed in attacked bolls. This appears to be a matter of malnutrition, the attacked seed making demands on the supply of the plant food to such an extent that nearly all the seeds in the boll are deprived of a portion of their nutriment.

LOSS IN WEIGHT OF SEED.

As the amount of seed destroyed or practically destroyed by *P. gossypiella* was found to assume proportions worthy of considerable notice, an attempt was made to ascertain the exact loss by weight caused in this manner. From material picked during the year, samples of seed cotton were accurately weighed, hand-ginned, and the seed examined individually and weighed, with the following results:

TABLE XIII.—Loss by weight to seed when hand ginned.

Sample.	Weight of sample.	Total number seed.	Sound seed.			Damaged seed.				Lint.	
			Number of seed.	Weight in grams.	Average weight per seed in gram.	Number of seed.	Weight in grams.	Average weight per seed in gram.	Loss in weight per seed in gram.	Weight in grams.	Per cent.
First pick, Zaragosa.	458 gms. (1 lb.)	2,438	2,282	252.65	0.1107	156	8.80	0.0561	0.0546	158.12	34.5
Second pick, Zaragosa.	do....	2,855	2,388	244.38	.1023	467	34.40	.0736	.0287	159.5	34.8
Third pick, San Isidra.	do....	3,678	1,753	180.20	.1027	1,925	125.30	.0651	.0376	141.5	31

Table XIII shows there was a smaller number of seeds in the sample from the first pick but that the individual seeds were heavier and the percentage of lint in the two samples was practically the same.

The damaged seed from the first pick weighed less per seed than from the second pick, and the damage per seed from the first pick was greater than in the second pick. This is probably because the bolls from the first pick were attacked when they were greener and the seeds were attacked when they were more immature than in the other picks. There is no indication that the number of seeds per boll is reduced on account of pink bollworm attack, as pointed out by Gough. Unfortunately, the sample of the third pick is from a different plantation and is not quite comparable with the other samples. It may be pointed out, however, that the average weight of the sound seed in the second and third picks is almost the same and that the loss in the individual attacked seed is greater in the third than in the second pick. This is thought to be because a much larger number of larvæ had prepared to hibernate in the third pick and a hibernating larva needs all the available space, especially in the single seed, and had eaten out the kernels of the seed cleaner to prepare this space. From the data given in Table XIII the loss in weight of the seed in the different picks can be calculated, and this is summarized in Table XIV.

TABLE XIV.—*Summary of table showing the loss in weight of the seed from the different picks due to pink bollworm attack.*

Pick.	Actual weight of seed (grams).	Loss in weight of infested seed (grams).	Corrected weight of seed (grams).	Per cent of loss in infested seed.	Per cent of total seed lost.	Remarks.
First.....	261.45	8.42	269.88	3.1	1.24	First pick=40 per cent crop. Second pick=40 per cent crop. Third pick=20 per cent crop.
Second.....	278.78	13.40	292.18	4.6	1.84	
Third.....	305.50	72.38	377.88	19.1	3.82	
Total.....					6.90	

Table XIV shows a loss of 3.1 per cent in the weight of the seed from the first pick, 4.6 per cent of the second pick, and 19.1 per cent in the third pick. The data secured in 1919 showed that 40 per cent of the crop was harvested in the first pick, 40 per cent in the second, and 20 per cent in the third. The losses in the seed from the different picks when given their proportionate weights with respect to the proportion of the total crop harvested in each pick show that 1.24 per cent of the total seed was lost in the first pick, 1.84 per cent in the second pick, 3.82 per cent in the third pick, or that a total of 6.90 per cent by weight of the seed is lost due to the attacks of the pink bollworm in the pickable cotton.

When the above-mentioned field samples of seed cotton were ginned the seed of the first, second, and third picks were placed in separate piles. Using a 20-liter measure, an equal number of weigh-

ings were made of the seed from each pick to determine the loss in weight between the seed of the different picks (Table XV).

TABLE XV.—*Weight of even number of containers of cotton seed for each pick.*

Sample No.	First pick.	Second pick.	Third pick.	Sample No.	First pick.	Second pick.	Third pick.
	<i>Kilos.</i>	<i>Kilos.</i>	<i>Kilos.</i>		<i>Kilos.</i>	<i>Kilos.</i>	<i>Kilos.</i>
1.....	10.5	10.5	10.5	8.....	11.1	10.7	10.7
2.....	11.0	10.7	10.6	9.....	10.9	10.9	10.5
3.....	11.1	10.6	10.6	10.....	11.0	10.5	10.6
4.....	11.3	11.0	10.5				
5.....	11.1	10.9	10.6	Total.....	110.4	107.5	106.2
6.....	11.2	10.8	10.8	Average.....	11.04	10.75	10.62
7.....	11.2	10.9	10.8	Net weight.....	6.24	5.95	5.82

Weight of container, 4.8 kilos; container used=20 liters.

From Table XIV it is shown that there is 3.1 per cent loss in weight in the seed from the first pick; therefore the weight of one 20-liter measure (6.24 kilos) would be equal to only 96.9 per cent of the weight of sound seed, and the corrected weight of a 20-liter measure of sound seed should be 6.43 kilos.

From these data it is shown that there is a loss of 0.19 kilo in the seed of the first pick, 0.48 kilo in the second pick, and 0.61 kilo in the third pick. These losses reduced to a percentage basis would equal 2.9 per cent of the seed lost in the first pick, 7.4 per cent in the second pick, and 9.4 per cent of the third. But as 40 per cent of the crop was harvested in the first pick, 40 per cent in the second pick, and 20 per cent in the third pick, these figures when given their weighted values will equal 5.96 per cent of the total seed lost due to pink-bollworm attack.

This difference of 0.94 per cent between the figures representing the total loss in the seed when hand-ginned and when commercially ginned is explained by the fact that part of the damaged seed is broken in cleaning and ginning the cotton, and passes out with the cleanings, trash, and even in the lint. It is thought, therefore, that the figure given for the hand-ginned sample, 6.9 per cent, represents more nearly the actual loss in the seed of the pickable cotton than does the figure 5.96 per cent obtained from the commercially ginned sample.

LOSS IN QUANTITY AND QUALITY OF OIL.

Besides the losses in the weight of the seed, there is also an additional loss in quantity and quality of the oil produced.

Because of the danger of introducing the pink bollworm into the United States, it was thought advisable not to bring seed out of Mexico for analysis. Samples were taken from the different field samples as ginned and given to the chemists of the largest oil mill in the Laguna district. Owing to the unsettled conditions prevailing in that section of Mexico during 1920, reports on these samples have not been received.

Willcox (?) states that there is marked reduction in the quantity of oil produced and that the quality is of an inferior grade.

NONPICKABLE COTTON.

It is in this class that the major portion of the gross damage occurs. As has been previously stated, there is a certain percentage of the cotton damaged to such an extent as to render it unfit for picking. This cotton naturally is left on the plants after the pickings are finished.

An effort has been made to determine the exact portion of the crop that is affected in this manner. By selecting what appeared to be average-sized plants (according to the number of bolls per plant, etc.) in fields of several different average plantations, about 3,000 plants were examined after the cotton had been picked. These plants were examined individually, the total number of bolls on each plant and total number of bolls lost on each plant due to attack of the pink bollworm being recorded. In counting the total number of bolls an empty burr was counted as a boll, and in the calculations has the weight of a perfectly sound boll.

In counting "bolls lost," only bolls or portions of bolls which showed plainly that their damage was caused by the pink bollworm were taken into consideration. Bolls or portions of bolls that showed themselves to be unfit for picking because of conditions other than the pink bollworm, such as those attacked by the common bollworm, *C. obsoleta*, or injured by water, heat, and dryness, were counted as sound bolls (Table XVI).

TABLE XVI.—*Loss to crop in nonpickable cotton caused by the pink bollworm.*

Place.	Total plants.	Total bolls.	Total bolls lost.	Per cent damaged
Hormiguero.....	248	6,737	1,066	15.82
Alvia.....	453	14,977	2,618	17.48
La Concha.....	503	15,117	2,942	19.46
San Isidera.....	454	20,112	3,768	18.73
Zaragosa.....	450	10,428	2,544	24.39
Rosas.....	450	9,282	2,318	24.97
Barcelona.....	300	6,297	1,325	21.04
Total.....	2,858	82,950	16,581	141.89
Average.....				19.98

Table XVI shows that of 82,950 bolls produced by 2,858 plants 16,581 were lost, making a total of 19.98 per cent damage in the non-pickable cotton due directly to the attack of the pink bollworm. The plantations on which these figures are based represent a true average of the entire Laguna. In addition to these plantations, a number of other places were visited in different parts of the Laguna and the amount of damage found ranged from 15 to 25 per cent, with an average of approximately 20 per cent loss due to the pink bollworm, which substantiates the accuracy of the foregoing estimates.

SUMMARY OF DAMAGE BY THE PINK BOLLWORM.⁴

- (1) Loss in squares and blooms: 26.8 per cent of the squares and blooms shed.
- (2) Loss in pickable cotton:
 - Lint: Deterioration in quality.
 - Seed: Is reduced 6.9 per cent in weight; quantity and quality of oil also reduced.
- (3) Loss in nonpickable cotton: 19.98 per cent of entire crop rendered unpickable.

The damage to the nonpickable cotton and the loss by weight in the seed in the pickable cotton can be reduced to a monetary basis. Assuming lint to be worth 30 cents per pound and seed worth \$60 per ton, the value of 500 pounds of lint would be \$150 and 1,000 pounds or $\frac{1}{2}$ ton of seed would be worth \$30, or a total of \$180 per bale. For every bale picked there is 19.98 per cent of the seed and lint left in the field as nonpickable cotton, or, in other words, the amount of cotton actually picked represents only 80.02 per cent of the crop if no pink bollworms were present. Then the value of the crop produced would be \$224.90 rather than \$180. The loss of 19.98 per cent of the potential crop (\$224.90) is equal to \$44.93 per bale. In addition to this there is 6.9 per cent loss by weight in the seed of the pickable cotton (which represents the 80.02 per cent of the bale not included in the 19.98 per cent loss or nonpickable cotton), which amounts to \$2.07. Therefore the total loss is \$47 or 20.89 per cent of the value of the bale.

The calculable loss that can be specifically stated on a definite percentage basis is 20.89 per cent. In addition to this figure there should be added the losses incurred in the shedding of the squares, deterioration in the quantity and quality of the oil in the seed, and the weakening and irregularity of the staple in computing the total damage caused by the pink bollworm.

FOOD PLANTS.

While cotton (*Gossypium* spp.) is by far the most favored food plant, a number of other plants have been recorded as host plants of the pink bollworm. Maxwell-Lefroy (2) records a species of Hibiscus and the oily seed of trees (species not given) in India; Fullaway (3) reared a single specimen from milo (*Thespesia populnea*) in Hawaii;

⁴ Damage during 1920.—The damage to the Laguna crop by the pink bollworm was unusually severe during 1920. Frost did not come in 1919 till very late and this was followed by a mild winter, which allowed a large percentage of the hibernating larvæ to pass the winter successfully. The fields were examined during the latter part of June, and it was very evident that the infestation in squares and young bolls was heavier than it had been in 1918 or 1919. The cotton was also further advanced and was growing rapidly, with very good prospects for a large crop. About this time there were severe outbreaks of aphids (*Aphis gossypii*), thrips, and rust (*Accidium gossypii*) which checked the growth of the plants and gave them a setback from which they never recovered. This caused the plants to produce very few bolls, and the infestation by the pink bollworms and the percentage of loss have consequently been very high. Estimates made in November showed that the pink bollworm had injured 31.3 per cent of the crop so badly that it was rendered unfit for picking and that there was 7 or 8 per cent additional loss attributable to the insect by the lowering of the quantity and quality of the pickable cotton, or a total of 38 to 39 per cent loss of the crop.



PINK BOLLWORM.

Larvæ feeding in the walls of the pods and seed of okra.

Busek (8) bred the pink bollworm from *Gossypium tomentosum* in Hawaii, but did not find it in milo; King (9) reports it from hanbuk (*Abutilon* sp.) in Africa; and Gough (12) records mallow (*Malva* sp.). Willcocks (7) states that the food plants in Egypt are bamia or okra (*Hibiscus esculentus*), teal or hemp (*Hibiscus cannabinus*), and hollyhock (*Althaea rosea*).

A number of malvaceous plants were grown beside heavily infested cotton on the laboratory grounds and several became infested. Okra (*Hibiscus esculentus*) became rather heavily infested in every instance when grown in close proximity to cotton. Table XVII is a complete record of all the seed pods grown on 30 plants at the laboratory during the season of 1919. From August 14 to December 3, 590 seed pods were examined with the following results: 66.7 per cent were infested with live larvæ and pupæ, and the total infestation, including seed pods that were unmistakably infested but in which no larvæ or pupæ were found, was 73.8 per cent. The infested seed pods averaged 2 larvæ, pupæ, and exit holes.

TABLE XVII.—Seed-pod examination of Okra (*H. esculentus*).

Number of pods.	Pods infested.		Infestation.			Number of infested pods without larvæ or pupæ present.	Number of exit holes.	Remarks.
	Number.	Per cent.	Larvæ total.	Number of pupæ.	Pupæ and larvæ.			
38	11	28.9	9	0	9	3	0	Green pods.
33	9	27.2	9	0	9	1	0	Do.
60	36	60.0	48	0	48	1	0	Do.
50	35	70.0	85	0	85	3	0	Do.
100	69	69.0	105	0	105	13	25	Do.
100	79	79.0	106	5	111	13	37	Do.
50	45	90.0	92	4	96	2	13	Dry pods.
84	66	78.5	147	5	152	5	8	Do.
20	12	60.0	37	0	37	1	0	Do.
20	17	85.0	35	0	35	1	1	Do.
35	15	42.8	21	0	21	0	0	Green pods.
590	394	66.7	694	14	708	43	84	

From this one observation it seems that when attacking okra the pink bollworm is more inclined to pupate in the seed pods than in the bolls when cotton is attacked. No plausible explanation can be given as to why this should occur.

The manner of attack and feeding habits in okra are essentially the same as in cotton, but no larvæ were ever found feeding in the flower buds or flowers.

Double seeds or three or four seeds are frequently webbed together in much the same manner as double seed in cotton, though the work is not so clean and particles of frass are usually found attached to them. Plate IV shows full-grown larvæ feeding in okra pods.

One important point to be determined is whether the species is able to sustain and perpetuate itself on okra alone as a food plant. Two

large screen cages were constructed over heavily infested okra in the fall of 1918. The entire plants with the fruits attached were left in the cages during the summer of 1919. Repeated examinations were made of all fruits formed during 1919 and no infestation ever developed from the hibernating larvæ. The protection afforded by the okra is not as good as the protection afforded by cotton. The seed pods crack open on drying and the seeds with the larvæ webbed up in them drop to the ground, the larvæ becoming subject to the detrimental effects of water and attacks of insect enemies.

Under the same conditions hollyhock (*Althaea rosea*), a very common ornamental flower, was found to be subject to the attack of the pink bollworm larvæ, the insects being found in the buds, flowers, and seed pods.

Hibernating cages were also constructed over hollyhock plants and experiments conducted in the same manner as with okra with negative results. No reinfestation occurred from hibernating larvæ.

The flower buds, flowers, and seed pods of *Hibiscus syriacus* were attacked by the pink bollworm, the manner of attack and feeding habits being the same as in cotton and okra. The infestation in the flower buds was light, but the seed pods were nearly all infested and some contained several larvæ.

One pink bollworm larva was taken from a seed pod of the Confederate rose (*Hibiscus mutabilis*).

Seeds from 25 species of malvaceous plants were collected in southern Texas and planted in close proximity to cotton at Ciudad Lerdo. Of this number only the following species grew: *Hibiscus coccineus* Walt., *Hibiscus militaris* Cav., *Hibiscus lasiocarpus* Cav., *Malvastrum americanum* (L.) Terr., *Sida spinosa* L., *Wissadula lozani* (Rose) Fries, and *Kosteletzkya virginica* L. Some of these have small seed pods and are not well adapted to the feeding habits of the larvæ, but the following species were attacked by pink bollworms.

Only one plant of *Hibiscus coccineus* grew. It developed 7 seed-pods and 5 of these were infested.

Hibiscus militaris was attacked both in the flowers and seed pods. The same rosette appearance takes place in the infested flower as in upland cotton.

Kosteletzkya virginica was also attacked. The plant is a very profuse bloomer, but the seed pods are rather small to be well adapted for the larvæ, though two full-grown larvæ were found in seed pods.

Malvastrum americanum was infested. One specimen was taken in a seed pod.

A species of *Malva* (*Malva parviflora* L. ?) grows rather abundantly along the borders of the fields in the Laguna, but was never found to be infested under natural conditions. The seed pods are too small to be well adapted for pink bollworms, though larvæ can reach maturity in a single pod.

DISPERSAL.

The most important factor in the dispersal of the species is man. By his transportation of cotton seed and cotton products he has carried the insect from its original home to all parts of the cotton-producing world. Once it is established, local dispersal from one field to another is also by flight, and in some instances the carriage of the larvæ by water is of importance.

CARRIAGE OF LARVÆ IN SEED FOR PLANTING AND OTHER PURPOSES.

The transportation of infested seed by man from place to place is the usual means by which this insect is carried to new localities. It was introduced into Mexico in 1911 with seed for planting; into Brazil in 1911-1913 with seed for planting; and more recently into certain parts of Texas with seed in cotton and seed for milling purposes. From what has already been stated concerning the habits of the pink bollworm, it is evident that seed from an infested field is sure to contain a certain percentage of infestation, and it is known that the resting larvæ can live for at least 2 years in such seed. It is thus seen that the larvæ are admirably adapted for transportation over great distances in this way. Seed, moreover, is often incidentally carried with other products. Railroad cars which have been used for shipping cotton seed are a very dangerous example of this. Seed will usually be found in the cracks and corners and between the walls of the car. Numerous instances of this have been noted, particularly by inspectors at border points, where live pink-bollworm larvæ were taken from cars which had been used for seed in the Laguna district and later used for exportation of other products. Bales of cotton often carry seed and as many as several hundred seeds have been found mixed with the lint and attached to the bagging. Cotton waste and used cotton bagging are other items usually having seed attached to them. Cotton pickers in Mexico often move from plantation to plantation. It is a common practice with them to carry their own picking sacks and among their belongings seed cotton and cotton seed are often found. These and similar practices are common means by which the insect is carried.

FLIGHT AND CARRIAGE OF ADULTS.

While the moth of the pink bollworm is small, it has ample wing power for its size and is capable of quick, darting flight. When disturbed during the day it flies only a short distance and hides under the nearest object. On the other hand, several hundred moths were liberated on top of the house where a light breeze was blowing, in the morning and at dusk. About half of those liberated in the morning flew only a few feet before settling down, while the others flew upward and away as far as the eye could follow them. Those liberated at dusk nearly all flew upward and away till lost to sight. In all cases they flew with the wind and not quartering to it, as some insects do. Up to the present time no conclusive data have

been accumulated along this line, due to the nocturnal habits of the moth and the fact that in Mexico it was so generally distributed that no uninfested isolated fields were found.

The average duration of the moth stage in captivity is about 14 days. If the moth flies only a short distance before coming to a rest, it would appear certain that it may again proceed for another short distance. If there were nothing to influence the direction of its flight, it might fly in any direction and as likely as not return to its original starting point; but if the direction of the flight is influenced by the wind, as it was in our observations, it would fly with the wind, and where there is a prevailing wind from one direction the moth would be carried in the same general direction farther and farther from its starting point and might cover a considerable distance before dying. In the eradication work in Texas a 5-mile non-cotton zone around infested territory is used to prevent dispersal by flight, and it is thought this zone is reasonably safe. The moths have seclusive habits, and frequently hide in cracks, crevices, and dark corners. At the railroad stations in the Laguna cars stand upon the side tracks within a few yards of the cotton fields for days or even weeks at a time while being loaded and unloaded. Trains stop for long periods of time near the fields to unload supplies, and when these stops are made at night, when the moths are flying about, it is possible that some of the moths might secrete themselves in the cars and later be carried to distant points. There is the same danger, though to a lesser degree, in vehicles passing cotton fields along the roads.

CARRIAGE OF LARVÆ BY WATER.

Cotton plants with bolls attached were often seen floating down the Rio Nazas when it was at flood stage, and old bolls are carried long distances when fields are overflowed. Some experiments were made at Dr. W. D. Hunter's suggestion to determine how long larvæ could survive exposure to water. Free larvæ with no protection whatever pupated and produced moths after being in water in tubes for 44 hours. Larvæ survived for several days after being in water longer, but none produced moths. Larvæ in cocoons survived 72 hours in water in tubes and free larvæ placed in pill boxes perforated with a needle produced one adult after 8 days' submergence in a pitcher. Pupæ did not survive as long as larvæ. Old bolls picked in January, 1918, and stored in the laboratory till April, 1919, were submerged in water and left floating on the surface of water in a trough. Larvæ pupated and produced adults after 7 days in both instances, but no adults emerged after 11 days in either case.

Several plants containing green bolls heavily infested were placed in the river and tied so that they could not float away. When there was enough current in the river to keep the plants floating at the end of the string the bolls were all washed away at the end of 4 to 5 days. When there was no current the plants sank to the bottom and all the larvæ were found dead in 3 days. It is quite likely, however,

that when plants are allowed to float free and move with the current the bolls will remain on the plants longer. When floating in this manner part of the plants are always out of water and, as they revolve more or less, the same bolls will not be submerged all the time and larvæ will survive more than 3 days. To determine how long larvæ would live in green bolls, sample bolls were placed in a trough and examined daily. The bolls floated and larvæ lived for 10 days. On the eleventh day all of the bolls sank to the bottom and were very rotten, and no live larvæ were found in them. The results of these experiments are summarized in Table XVIII.

TABLE XVIII.—*Effect of water on pink bollworm larvæ.*

Condition of exposure.	Number treated.	Time of exposure.	Per cent killed.	Remarks.
		<i>Hours.</i>		
Loose larvæ in tube of water...	5 larvæ.....	20	60	1 pupated afterwards.
	7 larvæ.....	44	70	2 pupated afterwards.
	20 larvæ and 3 pupæ...	120	100	Larvæ lived several days.
	30 larvæ.....	144	100	
Loose cocoons in tube of water...	10 larvæ.....	48	70	Heavy cocoons; 1 adult emerged.
	20 larvæ.....	72	90	Heavy cocoons.
	do.....	96	100	Do.
	10 larvæ.....	120	100	Do.
Double seed in tube of water...	10 double seed (5 larvæ.)	96	100	
	10 double seed (3 larvæ.)	124	66	2 larvæ alive.
	1 box.....	24	0	
	do.....	48	0	
Seed and cocoons in pill boxes perforated with needle..... (3 seeds and 2 cocoons in each box. Counted together).	do.....	72	40	
	do.....	96	0	
	do.....	120	50	2 pupated afterwards.
	do.....	<i>Days.</i>		
	do.....	6.5	40	
	do.....	8	60	
	do.....	11	100	
	do.....	15	100	
Bolls floating on water in trough. (Bolls picked in December, 1918, and stored in laboratory. Contained many dead larvæ not included in count.)	21 boxes.....	17	100	
	20 bolls (29 larvæ).....	7	80	Bolls covered with algæ and rotten.
	20 bolls (12 larvæ).....	11	100	Do.
	20 bolls (56 larvæ).....	14	100	Do.
	20 bolls (17 larvæ).....	17	100	Do.
	120 bolls (273 larvæ).....	18	100	Do.
	20 bolls (30 larvæ).....	7	77	2 pupated; bolls covered with algæ and rotten.
	20 bolls (113 larvæ).....	11	100	1 larva lived several days; bolls rotten.
Bolls submerged in water in trough (same kind of bolls as above).	20 bolls (46 larvæ).....	14	100	Bolls rotten.
	20 bolls (14 larvæ).....	17	100	Do.
	120 bolls (169 larvæ).....	18	100	Do.
		<i>Hours.</i>		
Green bolls submerged in slatted box in river.	10 bolls (37 larvæ).....	48	95	Bolls fermenting and very sticky.
	10 bolls.....	72	100	Interior bolls rotten.
	10 bolls.....	96	100	Badly rotted.
	10 bolls (40 larvæ).....	48	55	Bolls fermenting.
Plant with green bolls attached floating on surface of river, Sept. 13, 1919.	9 bolls (19 larvæ).....	72	98.4	Interior of bolls rotting.
	7 bolls (11 larvæ).....	96	46	All of live larvæ found in two bolls which were not submerged.
		<i>Days.</i>		
	20 bolls (122 larvæ).....	3	7.3	
143 green cotton bolls placed in container of water. Water changed daily.	20 bolls (125 larvæ).....	4	3.1	All dead in two badly decayed bolls.
	20 bolls (133 larvæ).....	5	6.3	Decaying.
	20 bolls (107 larvæ).....	6	60.7	Some in bad state of decay.
	15 bolls (84 larvæ).....	7	31.5	Do.
	16 bolls (73 larvæ).....	8	38.8	Some bolls rather small and badly decayed.
	10 bolls (61 larvæ).....	9	44.2	Bolls decaying rapidly.
	10 bolls (51 larvæ).....	10	60.7	Some still floating; badly decayed.
	6 bolls (43 larvæ).....	11	100.0	Badly decayed.
	6 bolls (29 larvæ).....	12	100.0	Very rotten.

In general, it may be said that larvæ will live in bolls submerged in water or floating on the surface of the water till the bolls themselves are thoroughly rotten. This may be a week or more, depending upon the condition of the bolls. The old dried bolls and larvæ webbed up in bits of rubbish are particularly likely to carry an infestation a long distance, for they float more readily than green bolls. One of the large plantations was considering dividing their property into zones which would be planted in cotton only every third or fourth year in order to reduce the damage by the pink bollworm, but the danger of reinfestation by irrigation water was considered so great that it was not adopted.

NATURAL CONTROL.

From the data collected in 1918 and 1919, it is concluded that the maximum infestation and the maximum damage to the cotton of the Laguna have been reached by this time, except for slight yearly variations due to climatic conditions which may have some effect on the development of the pink bollworm and its attack on the cotton. It is the belief of the plantation owners that the damage or loss to the crop has remained about the same since 1916, or that the maximum had been reached at the end of five years from the time of introduction.

MORTALITY OF NEWLY-HATCHED LARVÆ.

It has been shown in Table III that 47.1 per cent of the pink bollworm eggs are not deposited on the squares or bolls. The larvæ from these eggs must crawl some distance before reaching food. In this migration they are readily attacked by insect enemies, are exposed to the hot sun, become weakened and exhausted, and eventually may succumb to starvation. It is thought that very few or possibly none of the larvæ from this 47.1 per cent of the eggs ever enter the squares or bolls. Many of the larvæ from the remaining 52.9 per cent of the eggs deposited on suitable parts of the plant never succeed in entering the bolls or squares either. To determine what percentage of the larvæ hatching from eggs deposited on the plants fail to enter the bolls or squares, five plants were examined. These records were carefully made. Every part of the plant was closely examined with a hand lens for eggs and eggshells. The larvæ, pupæ, and exit holes were also carefully counted and the mortality rate calculated from the number of eggshells found on the plants and the total infestation of the plants. The results are given in Table XIX.

TABLE XIX.—*Mortality of larvæ of P. gossypiella.*

Number of plants.	On plant.		Number of larvæ.		Pupæ found.	Exit holes.	Larvæ, pupæ, and exit holes.	Per cent mortality.	Remarks.
	Number of shells.	Number of eggs.	In squares.	In bolls.					
1.....	181	89	3	17	0	7	27	85.1	16 bolls on plant. 28 bolls on plant.
1.....	141	111	1	46	0	12	59	58.2	
1.....	190	115	6	84	0	24	114	40.0	
1.....	170	53	0	25	3	13	41	75.9	
1.....	103	143	2	39	0	15	57	44.7	
5.....	785	511	12	211	3	72	298	62.1	

From this table it is seen that the mortality varies from 40 to 85.1 per cent with an average of 62.1 per cent. If it is assumed that none of the larvæ from the 47.1 per cent of the eggs laid on other parts of the plants ever succeed in entering the bolls or squares, this would still leave 15 per cent of the larvæ from eggs laid on the squares and bolls unaccounted for. Since many eggshells had undoubtedly fallen from the plants examined, this percentage of mortality (62.1 per cent) is smaller than what actually occurs.

To determine what percentage of the eggs laid on the bolls are lost, 16 samples of 25 green bolls each were examined, the number of eggs laid on them counted, and the total infestation found (Table XX).

TABLE XX.—*Mortality of pink bollworm larvæ from eggs laid on bolls.*

Number of bolls.	Eggs.			Larvæ.				Exit holes.	Pupæ.	Total infestation.	Per cent of larvæ from eggs laid on bolls recovered in bolls.
	Tip.	Base.	Total.	First.	Second.	Third.	Fourth.				
400.....	61	4,958	5,019	190	347	442	1,005	386	1	2,371	45.8
Average.....	0.15	12.4	12.5	0.47	0.87	1.1	2.5	0.96	.....	5.92	.....

There were 5,019 eggs and eggshells on the bolls. If larvæ from all these eggs had hatched and all the larvæ gone into the bolls, there would have been an average infestation of 12.5 larvæ per boll, whereas an average of a little less than 6 larvæ was actually found. These examinations were made in October and later examinations showed that the maximum infestation ever reached was an average of 7 per boll.

These figures indicate that about half of the larvæ from eggs laid on the bolls themselves never succeed in entering them. In Table III it was shown that 51.7 per cent of the eggs were laid on the bolls and appendages, and if only half of these successfully enter the bolls this would be equal to 25.8 per cent of the total eggs. This loss of

25 per cent, in addition to the 47.1 per cent laid on other parts of the plants and assumed to be lost, would bring the total mortality of young larvæ up to 72.9 per cent. This figure (72.9 per cent) is thought to approach more closely what actually takes place in the field than that of 62.1 per cent based on the number of empty shells found. This is borne out by laboratory experience where the mortality was 90 per cent or more.

Once the larvæ are inside the bolls there is very little or no mortality during the summer months.

MORTALITY OF HIBERNATING LARVÆ IN THE FIELDS,

There is a very heavy mortality in hibernating larvæ left in the fields during the winter, especially when the fields are irrigated. Examinations of old bolls picked up in the fields showed that about 80 to 90 per cent of the larvæ survived till February, and that the mortality rapidly increased from this date onward. The mortality varies greatly in different samples, but by the end of March it is difficult to find any live larvæ in the scraps picked up on the ground in the fields. There are still live larvæ present, but the old bolls have broken up, scattered, and in cultivated fields are difficult to find. On March 13, 1918, only 3 live larvæ were found from a bushel of old bolls and trash picked up in a lightly infested field at San Pedro. On April 16, 1919, no live larvæ were found in the old bolls left on the ground after cattle had grazed over the fields at Tlahualilo, but about 5 per cent were still alive in the bolls left on the stalks.

To secure more data on this point, two series of experiments were started on November 26, 1918. One experiment was under as nearly normal irrigated field conditions as possible and the other under non-irrigated conditions. The fields in the Laguna are usually irrigated in November, December, or January, when cotton follows cotton, as it does on most plantations. When fields have been lying fallow for a season, the water is applied any time during the year when it is available. About 3 feet of water is placed on the fields and allowed to soak in. This requires from one to several months, depending upon the character of the soil. In the experimental plot irrigation was started on December 2 and continued till December 8, when the motor burned out. Water was again applied on December 23, 1918, and continued daily until January 22, 1919. On account of the small amount of electric current available, the plot could not be filled 3 feet deep, but the daily application of a few inches of water kept the ground thoroughly wet and covered with water at least part of each day.

In each of the series the larvæ were exposed under wire cages in bolls in a single layer on the surface of the ground, in bolls buried 6 to 7 inches deep, and in double seed buried one-fourth inch deep in flowerpots which were set in the soil flush with the surface. More-

over, larvæ removed from all seed and lint were placed in screened boxes and flowerpots and allowed to enter the soil. These were also buried flush with the surface of the ground. A sample of the bolls used was examined at the time and found to contain an average of 6.64 fourth-instar and 0.03 third-instar larvæ per boll. The material was examined at different dates and the results are given in Table XXI.

TABLE XXI.—*The mortality among hibernating Pectinophora gossypiella larvæ under different field conditions.*

Ex- peri- ment No.	Conditions of exposure.	Examination.					Remarks.
		Date.	Live larvæ.	Dead larvæ.	Live pupæ.	Pupal skins.	
557	300 larvæ removed from seed and lint and buried in wooden box of soil in irrigated plot.	1919. June 11.....	0	2	0	0	61 empty dirt cells around side of box.
558A	50 larvæ in flowerpot, same as 557.	May 10.....	0	Several.	0	0	
558C	Same as 558A.....	June 10.....	0	3	0	0	
558B	Same as 558A.....	June 11.....	0	0	0	0	
558D	50 double seeds buried in flowerpot on irrigated plot.	June 11.....	0	0	0	0	Seed well rotted.
560	300 larvæ removed from seed and lint and buried in wooden box of soil in nonirrigated plot.	June 12.....	12	.....	3	2	Larvæ webbed up on side of box.
561A	50 larvæ in flowerpot, same as 560.	May 10.....	28	1	1	1	Larvæ in cocoons.
561B	Same as 561A.....	June 11.....	0	7	0	0	
561C	50 double seeds in flowerpot on nonirrigated plot.	June 12.....	6	.....	1	3	Seed well rotted.
559A	200 green and dry bolls buried 6 to 7 inches deep on irrigated plot.	Mar. 10 (10 bolls). Apr. 24 (10 bolls). May 16 (50 bolls). June 6 (130 bolls).	0 0 0 0	65 48	0 0 0 0	0 0 0 10	Bolls rotting badly. Very rotten and fallen to pieces. Fallen to pieces. Bolls so rotten difficult to pick from soil.
559B	200 green and dry bolls left on top of ground on irrigated plot.	Mar. 10 (10 bolls). Apr. 24 (10 bolls). May 15 (50 bolls). June 4 (116 bolls).	39 20 74 51	29 36 194 344	0 1 2 6	0 3 2 18	Bolls in good condition. Do. Some of bolls getting rotten, but those which had opened when experiment began still in good condition.
562A	200 green and dry bolls buried in soil 6 to 7 inches deep on nonirrigated plot.	Mar. 11 (10 bolls). Apr. 24 (10 bolls). June 7 (180 bolls).	52 13 0	0 13 0	0 2 0	0 10 0	Bolls badly rotted. Badly rotted and could not separate bolls. Thoroughly rotten.
562B	200 green and dry bolls left on top of ground on nonirrigated plot.	Mar. 11 (10 bolls). Apr. 24 (10 bolls). May 15 (50 bolls). June 7 (50 bolls). July 25 (25 bolls). Aug. 22 (80 bolls).	68 54 83 152 0 0	26 28 137 188 100 0	0 0 0 2 0 0	0 0 6 11 7 0	Bolls in very good condition. Do. Do. Do. Do. Do.

Table XXI shows that no live larvæ were found during May and June among those removed from seed and lint or in double seed buried in the irrigated plots (Experiments Nos. 557 and 558 A to D), and that 12.8 per cent were alive or had emerged as moths under the same conditions in the nonirrigated plot (Experiments Nos. 560 and 561 A to C). No live larvæ were found in bolls buried in irrigated plots from March 10 (the first examination) until June 6 in Experiment No. 559 A, and none in bolls buried in nonirrigated plot (Experiment No. 562 A) after April 24. The surrounding soil had been irrigated and when the last examination was made on June 7 the soil in the nonirrigated plot was found moist about 3 inches below the surface from water that had seeped in from below. From this experiment 6.2 per cent survived till April 24. There was less mortality in the bolls when left on the surface of the ground than when buried. In the irrigated plot (Experiment No. 559 B) live larvæ were found in bolls left on the surface of the ground at the last examination on June 4, 1919, and 9.7 per cent had survived or previously emerged as moths on this date. On the nonirrigated plot (Experiment No. 562 B) 50 per cent of the larvæ in bolls on the surface were alive on June 7, 1919. At the next examination, on July 25, all of the larvæ were dead.

In all of the experiments, especially the later examinations, many of the larvæ were not recovered because the dead larvæ were so decomposed they were not recognizable. Very few if any escaped, for the buried bolls had close-mesh wire screen over the top and along the sides, extending below the level of the bolls. The earth surrounding the material was carefully sifted and larvæ and pupal skins found here counted with the others. The percentages of mortality for the bolls are based on the number of larvæ found in the samples at the beginning of the experiments. This is not absolutely accurate, because the number of larvæ may vary considerably in individual bolls, but it is the most reliable figure to use inasmuch as the actual number of dead larvæ could not be determined.

It is seen that the mortality increases as the season advances, even where the conditions were most favorable, no live larvæ being found as late as July 25, and that the mortality in all the experiments was greater when the larvæ were buried than when they were left on the surface, and greater when the plots were irrigated than when left dry. These experiments also show that the greatest danger for starting a new infestation from material left in the fields is the old bolls left on the surface of the ground. Over 9 per cent of the larvæ in these bolls on the irrigated plot survived till June 4 and 50 per cent survived in the nonirrigated plot. At this season the cotton will be large enough for oviposition to begin. Under the usual field conditions the irrigated lands will have been cultivated before this date

and the mortality increased by breaking up and burying the bolls. On the other hand, the bolls float on water and the wind frequently blows them against the borders on one side of the field, where they are piled up several inches or more deep. This concentration keeps some of the bolls out of the water and affords more protection for the bolls in the interior of the pile against heat and cold. If the fields are not irrigated it means they will not be planted the following year and such fields are usually grazed by goats, cows, and burros, which eat many of the bolls.

Whether or not the results obtained in these experiments during only one winter⁵ hold true for what actually takes place in the Laguna it is impossible to say, but they indicate beneficial results from irrigation and burying the bolls. That a very heavy mortality, probably more than 95 per cent, does take place in the fields is shown by field examinations of the bolls and the very light infestation in the early part of the season. There are such enormous numbers of larvæ hibernating in the fields that the crop would be entirely destroyed if the mortality was not very high.

Willcocks (7) in Egypt left bolls out of doors exposed to the sun on the surface of dry ground and ground that was watered periodically (three waterings). He found a very high mortality during April, May, and June, and all the larvæ were dead on June 25. There was a slightly higher mortality among the larvæ in the watered bolls and all the larvæ were dead on April 8, while some survived in the dry bolls till May 3. His figures "most certainly show that the chance of resting-stage pink bollworms surviving in the bolls fully exposed to the sun on the surface of dry sheraki land in May, June, and July is a remote one." He buried another lot of bolls on November 24 in damp soil in boxes. Some of these were kept dry and others wet. Some were stored indoors and others outdoors, though none were in direct sunlight. There was less mortality in the buried bolls than in those left on the surface exposed to the sun, and he says, in speaking of wet conditions, "this does not seem to be materially disadvantageous to the pest." In all of the buried bolls there was a decided emergence of the larvæ to the top of the soil, which began as soon as the bolls were buried (November 24) and continued intermittently in some cases where the bolls were kept dry till the following November. Water hastened this larval emergence when applied in the fall or the following spring, but though the bolls were badly rotted the larvæ were still able to remain in them, and spun up in their almost water-tight cocoons during March, April, and May.

In our experiments in Mexico, larvæ survived better in bolls on the top of the ground than when buried and better when left dry than when irrigated. In Mexico the temperature was never as high

⁵ These results were substantiated by experiments during the winter of 1919-20.

as it is in Egypt in May and June (107° and 111° F.) and our bolls received some protection from the sun by the screen covering of the irrigated bolls and the cheesecloth covering over the nonirrigated bolls. Furthermore, our bolls were probably kept wetter during the 30 days when they were wet than Willcocks's were, but his were kept wet for a longer time. There was but very little larval emergence in any of our bolls. This is shown by the large numbers of dead larvæ found *in situ* in the earlier examinations, when they were still recognizable, and by the few larvæ or pupal skins found in the surrounding soil. There was more larval emergence from the bolls in the irrigated plots where 12 pupal skins were found in the soil than in the nonirrigated where only 2 or 3 were found. About half of the larvæ recovered in the bolls were in the lint, but no count was kept of this point and it is not known whether there were more than are usually found in lint in the bolls in the fields during the fall or not. In the case of the double seeds in the irrigated plot the following note was made: "Earthen cells were noticed in a few instances, apparently some of the larvæ left the seed." In the double seed on the nonirrigated plot 4 pupal skins were found in the soil.

On March 11, 1919, 100 bolls which were picked on December 7, 1918, and stored in the laboratory till this date were buried 1 to 2 inches deep in a box of soil and wet thoroughly. The box was sprinkled often enough to keep it thoroughly wet for 30 days. On April 11 the contents were carefully examined and 35 live larvæ and 90 dead larvæ were found in the bolls and only 4 larvæ and 2 pupæ in the soil. Willcocks (?) found a very sudden increase in the number of larvæ emerging to the surface in a box of bolls buried in dry soil and watered in the spring.

Unfortunately a sufficiently large sample of bolls for our check was not examined at the beginning of the experiment to determine the mortality until this date, and the check sample examined at the end of the experiment contained more live larvæ than at the beginning. The indications were, however, that the treatment had killed a large number of the larvæ. The bolls were totally rotted and larvæ which were dead at the beginning of the experiment were unrecognizable at the finish.

MORTALITY OF HIBERNATING LARVÆ IN STORED SEED.

The number of larvæ found in the ginned seed is very small compared to the number found in the bolls when the cotton is picked. In the Laguna the seed cotton is passed through cleaners or beaters before it goes to the gins to remove the trash and dirt. This causes most of the larvæ to leave the lint and many are undoubtedly driven from the seed also during the process. Larvæ are thrown out by the thousands with the trash that comes from the later pickings, and in some cases the pile of trash and the sides of surrounding buildings

are pink with crawling larvæ. Many of the double seeds are torn apart in the cleaner and gin, though some go through unharmed. It is extremely disappointing to look for larvæ in seed which comes from heavily infested cotton. In such seed in the winter or spring one can rarely collect more than 75 to 100 live larvæ in the course of an eight-hour day. Ten samples of 2,500 seeds each were taken on different occasions during February and March, 1918 and 1919, from seed houses, examined seed by seed, and only 9 live larvæ were found.

For our rearing work larvæ were removed by hand from the bolls and placed in fruit jars with seed to pass the winter. Table XXII shows that the mortality among larvæ removed from bolls in November and stored in the laboratory during the winter of 1918 and 1919 was 22.6 per cent and that 0.4 per cent were still alive November 20, 1919, when the work was discontinued.

Other larvæ were disturbed as little as possible and were left in the double seed where they had prepared to spend the winter. The double seed were picked from the lint by hand and stored in the laboratory under the same conditions as the others. Table XXIII shows that there was 16.2 per cent mortality among larvæ in double seed and that 4.4 per cent were still alive on November 20, 1919.

TABLE XXII.—*Mortality among larvæ removed from bolls and kept in the laboratory in a condition as near to that of stored seed as possible.*

Date collected.	Number entering resting stage.	Number emerged.	Per cent mortality.	Per cent emerged.	Number alive Nov. 20, 1919.
1918.					
Sept. 30.....	83	71	13.2	85.5	2
Nov. 13.....	281	191	31.6	68.0	2
Do.....	256	180	28.9	70.3	2
Do.....	269	153	43.1	56.9	0
Nov. 14.....	260	183	29.7	70.3	0
Nov. 15.....	282	220	22.0	78.0	0
Do.....	309	255	17.5	82.5	0
Do.....	239	201	15.4	84.1	1
Do.....	320	255	19.6	79.6	2
Do.....	299	244	17.7	81.6	2
Do.....	277	211	23.4	76.2	1
Nov. 16.....	260	193	25.0	74.2	2
Do.....	244	192	20.9	77.7	1
Nov. 17.....	265	242	8.6	91.3	1
Nov. 19.....	125	99	20.8	79.2	0
Total.....	3,769	2,890	-----	-----	16
Average.....	-----	-----	22.6	77.0	0.4 per cent.

The moths were removed daily and a record kept for each jar. The percentages used are based on the number of moths emerging and the number of dead and live larvæ found in the jar at the end of the experiment. As these larvæ were carefully removed by hand and stored indoors, the mortality was the minimum that can be expected and is much lower than in seed ginned and handled on a commercial scale. It is difficult to determine the mortality

in the seed warehouses, because the dead larvæ are so hard to find, but it is evident to one collecting larvæ that it is much higher in the early spring than in the fall. The mortality was 80 per cent among larvæ thrown out by the cleaners and stored indoors during the winter, and in this sample only the most active larvæ were used.

TABLE XXIII.—*Mortality among larvæ in double seeds removed from lint by hand and stored in jars in the laboratory.*

Date collected.	Number entering resting stage.	Number emerged.	Per cent mortality.	Per cent emerged.	Number alive Nov. 20, 1919.
1918.					
Nov. 15.....	206	182	8.7	88.3	6
Nov. 22.....	190	165	9.4	86.8	7
Nov. 23.....	184	157	8.1	85.3	12
Nov. 22.....	88	76	9.0	86.3	4
Do.....	61	41	22.9	67.2	6
Dec. 25.....	213	119	41.3	55.8	6
1919.					
Jan. 23.....	172	143	11.6	83.1	9
Total.....	1,114	883	.....	.....	50
Average.....	.....	.....	16.2	79.2	4.4 per cent.

MORTALITY OF LARVÆ PLANTED WITH THE SEED.

A screen-wire cage was built so that no infestation could interfere from the outside, and 100 double seeds were planted with sound seed in 30 hills to see what the infestation would be from larvæ planted with the seed alone. No infestation occurred during August, but from September 1 to November 7 the infestation went from 12 per cent to 96 per cent, with an average of 5.6 larvæ per boll on November 7. Thus it is evident that should all the larvæ left in the fields be destroyed either naturally or by artificial means, the infestation arising from the larvæ planted with the seed alone is sufficient to cause a considerable loss (Table XXIV).

TABLE XXIV.—*Infestation of pink bollworm from 100 double seeds planted in a cage.*

Date examined.	Per cent of bolls infested.	Average infestation per boll.			
		Larvæ.	Pupæ.	Exit holes.	Total.
1919.					
Aug. 1.....	0	0	0	0	0
Aug. 6.....	0	0	0	0	0
Aug. 22.....	0	0	0	0	0
Sept. 1.....	12.00	0.12	0	0	0.12
Sept. 30.....	84.00	2.20	0	0.96	3.16
Nov. 7.....	96.00	5.60	0	0	5.60

PARASITES AND PREDATORS.

What part of the mortality in the newly hatched larvæ is due to starvation, exposure to the sun, or falling from the plants, and what to predacious insects, could not be determined, but the toll

taken by the nymphs and adults of three species of small undetermined Hemiptera is evidently very high. The attacks on the small pink bollworm larvæ from these predators are so important that daily examinations of all food placed in the breeding cages was absolutely necessary. Often one small nymph would destroy the larvæ from a large number of eggs during the night.

The larvæ of a lace-wing, *Chrysopa rufilabris* Burm., attacks the newly hatched pink bollworm and also the larger larvæ in the flowers.

Only very rarely is a dead larva found inside a boll. The feeding habits within the green boll greatly reduce the chances of attack by parasites and predators during this period. When the exit holes are cut, or the boll begins to open, or when the larvæ are migrating to the ground, they are exposed to these enemies for a short time. This short period of exposure may account for the very few parasites found. Only three species and one specimen of each were found attacking the larvæ. They were the Hymenoptera *Habrobracon* sp., *Parisierola emigrata* Rohwer, and a small dipteran, *Tortriciophaga tortricis* Coquillett. The scarcity of these parasites during the two years proves very conclusively that no relief can be hoped for from this source.

The pupæ of the pink bollworm in Mexico were not attacked by parasites, so far as our observations show.

The small chalcid *Trichogramma minutum* Riley may prove beneficial in parasitizing the eggs of the pink bollworm, but it was not observed attacking the eggs until late in the season, and then only very rarely.

An outbreak of mites, *Pediculoides ventricosus* Newport, occurred on the hibernating larvæ in the laboratory in 1918. Steps were taken immediately to check them by burning all infested material. To what extent these mites occur in the seed houses was not determined.

REPRESSION.

FUMIGATION OF SEED.

From the known instances in which infestations have occurred from larvæ planted in the seed there can be no doubt of the danger of planting infested seed. Several methods of killing the larvæ in the seed have been used in Egypt and other places (10), but all fall into three classes: Immersion of the seed in some substance to kill the larvæ, treatment with heat, or fumigation with poisonous gases. Immersion of seed in liquids is obviously out of the question where tons of seed are used for planting on a plantation. In Egypt larvæ can be killed by exposing them to the heat of the sun. Preliminary experiments showed that the temperature in Mexico during the planting season was not high enough to kill the larvæ and that

cotton seeds are very poor conductors of heat. Machines (4, 6) have been perfected for passing the seed on an endless belt through air heated to 130° F. and houses have (7) been constructed for heating a mass of seed sufficiently high to kill the larvæ, but in Mexico fuel is scarce and very expensive, so fumigation with poisonous gases seemed the most economical and practical method to use.

A fumigation chamber of adobe bricks set in mud, the usual type of building in the Laguna, was constructed. The walls of this chamber were about 20 inches thick and were plastered on the inside and outside with cement. The floor was of brick set in mortar. During the fumigation the wooden door was closed and several thicknesses of wall paper plastered over the cracks. The size of the room was 5 by 8 by 10 feet, or 400 cubic feet. Three tons of cotton seed filled it about 5 feet deep. Experiments were made with seed placed in the room in bulk and in sacks. Carbon disulphid and hydrocyanic-acid gas were used.

CARBON DISULPHID.

Live larvæ, pupæ, and adults were placed at different depths in the seed, usually near the top, center, and bottom of the pile. The use of adults was discontinued after the first few experiments on account of the death of all the moths, while in the same experiments the mortality of the larvæ varied a great deal. Pupæ did not seem more difficult to kill than larvæ. Larvæ, and pupæ when they could be obtained, were placed in single, double, and triple pill boxes, at least 60 larvæ and sometimes more being used for each experiment. Larvæ in double and triple boxes were thought to be about as difficult to kill as larvæ webbed up in seed would be. Sometimes the larvæ would spin cocoons in the boxes before they were placed in the house, but such larvæ were killed along with the others. Where only a few larvæ were not killed they were always in the triple boxes on the bottom of the pile.

As only one lot of 3 tons of seed was available, the seeds were taken from the house and left exposed to the sun for several days after each experiment. When the seeds were returned to the house the boxes of larvæ were tied in a muslin bag and placed in position, the disulphid placed in shallow vessels on the top of the seed, and the door sealed.

Considerable difficulty was experienced at first in determining whether larvæ were dead or not. All of the larvæ would appear dead when removed, but they still retained their pink color and some of them would revive and pupate after lying in a comatose state for a week or more. Later all the larvæ were kept until we were absolutely sure whether they were dead or alive. Table XXV is a de-

tailed account of the fumigations that were made with carbon disulphid.

TABLE XXV.—*Preliminary fumigation experiments with carbon disulphid for P. gossypiella in cotton seed.*

Experiment No.	Dosage.		Length of exposure.	How seed was stored.	Location of larvæ.	Per cent killed in each location.	Total per cent killed.
	Pounds.	Cubic feet.					
			<i>Hours.</i>				
1	1	102	90	In sacks.....	Top sack.....	100	100
					Bottom sack.....	100	
2	1	161	48	do.....	Top sack.....	100	100
					Bottom sack.....	100	
3	1	289	48	do.....	Top sack.....	0	0
					Bottom sack.....	0	
4	1	161	23	do.....	Top sack.....	12	14
					Bottom sack.....	16	
5	1	161	23	do.....	Top sack.....	60	43
					Bottom sack.....	26	
6	1	161	48	In bulk.....	2½ feet deep.....	100	60
					4½ feet deep.....	20	
7	1	103	48	do.....	2½ feet deep.....	100	72
					4½ feet deep.....	45	
8	1	124	48	do.....	2½ feet deep.....	31	16
					4½ feet deep.....	0	
9	1	82	48	do.....	2½ feet deep.....	100	88
					4½ feet deep.....	75	
10	1	54	24	do.....	2½ feet deep.....	100	90
					4½ feet deep.....	80	
11	1	80	42	In bags.....	On top.....	100	100
					In center.....	100	
					On bottom.....	100	
					On top.....	100	
13	1	100	1 week.	In bulk 6 feet deep.	2 feet deep.....	100	91
					4 feet deep.....	84	
					6 feet deep.....	82	
					18 inches from top.....	100	
19	1	100	<i>Hours.</i> 48	In bulk 5 feet deep.	Middle.....	97.5	94
					Bottom.....	75	
20	1	80	48	do.....	Middle.....	100	100
					Bottom.....	100	
21	1	80	48	do.....	Middle.....	100	100
					Bottom.....	100	
22	1	80	48	do.....	Middle.....	100	100
					Bottom.....	100	
23	1	80	24	do.....	Bottom.....	100	100
					Middle.....	100	
26	1	80	12	do.....	Bottom.....	90	95
					Middle.....	85	
27	1	80	15	do.....	Bottom.....	80	82.5
					Middle.....	100	
29	1	85	24	do.....	Bottom.....	100	100
					Middle.....	100	
30	1	85	24	do.....	Bottom.....	100	100
					Middle.....	100	
31	1	90	24	do.....	Bottom.....	85	85
					do.....	60	

¹In Experiment No. 10 the larvæ were placed in glass tubes, which were closed with cork stoppers, making them approximately air tight.

In experiments 20, 21, and 22 all larvæ were killed with 1 pound of disulphid to 80 cubic feet in 48 hours. In order to shorten the time, experiments 23, 26, and 27 were made, and all the larvæ were not killed. All of the disulphid had not evaporated at the end of 12 and 15 hours in experiments 26 and 27, but it had evaporated in experiment 23 in 24 hours, and all the larvæ were killed, showing that 24 hours are necessary to evaporate and to secure maximum penetration of 1 pound of disulphid in 80 cubic feet. This was in

the summer time, when the temperature inside the house was 75° to 80° F. Experiments 13, 19, 29, and 30 were made to decrease the dosage needed. All larvæ were not killed in experiments 13 and 19, where the dosage was 1 pound disulphid to 100 cubic feet with long exposures, but all were killed in experiments 29 and 30, with 1 pound to 85 cubic feet and a 24-hour exposure.

Table XXVI is a summary of the carbon disulphid experiments. From these experiments it is seen that satisfactory results were obtained by using 1 pound of carbon disulphid to 80 cubic feet for 24 hours or longer when the seeds were not over 5 feet deep.

TABLE XXVI.—*Fumigation of cotton seed with carbon disulphid.*

Experiment No.	Dosage.		Exposure.	Per cent larvæ killed.	How seeds were placed.
	Pounds.	Cubic feet.			
			<i>Hours.</i>		
1	1	102	90	100	Seed in bags.
2	1	161	48	100	Do.
11	1	80	42	100	Do.
20	1	80	42	100	Seed in bulk, 5 feet deep.
21	1	80	48	100	Do.
22	1	80	48	100	Do.
23	1	80	24	100	Do.
29	1	85	24	100	Do.
30	1	85	24	100	Do.
26	1	80	12	95	Do.
19	1	100	48	94	Do.
13	1	100	168	91	Seed in bulk, 6 feet deep.
10	1	54	24	90	Seed in bulk, 5 feet deep.
9	1	82	48	88	Do.
31	1	90	24	85	Do.
27	1	80	15	82.5	Do.
7	1	102	48	80.5	Do.
32	1	90	24	60	Do.
6	1	161	48	51	Do.
5	1	161	23	37	Seed in bags.
8	1	124	48	17	Seed in bulk, 5 feet deep.
4	1	161	23	13.3	Seed in bags.

¹ Record doubtful.² Larvæ in corked vials.

HYDROCYANIC-ACID GAS.

The fumigation of cotton seed with hydrocyanic acid gas proved very unsatisfactory, as the gas is so light that it will not penetrate the seed more than a few inches. In some of the experiments an earthenware crock containing the sulphuric acid was set directly on top of the seed pile and the cyanid lowered by a string from the outside in the usual way. The penetration was so poor that a special generator was designed. A section of 10-inch pipe 14 inches long was fitted with gas-tight caps on both ends and a lead inner pot to hold the acid. The generator was placed outside the house below the floor level and the gas conducted to the inside, where it was allowed to escape in the bottom of the fumigation chamber through perforated pipes. It was hoped that the penetration upward would be greater than downward, but there was very little difference.

Table XXVII is a summary of the experiments with the use of hydrocyanic-acid gas. From these experiments it is seen that it is not practicable to use hydrocyanic-acid gas when the seeds are over 4 inches deep. It could not be recommended even when seed is in ordinary bags, for the center of a bag of cotton seed is more than 4 inches from the surface of the sack exposed.

TABLE XXVII.—*Fumigation of cotton seed with hydrocyanic-acid gas.*

Experiment No.	Position of generator.	Dosage per 100 cubic feet.	Exposure.	Per cent of larvae killed.	Remarks.
			<i>Hours.</i>		
17	Inside.....	2-2-4	2	100.0	Seed in bulk, 4 inches deep.
24	do.....	4-4-8	3	70.0	Seed in bulk, 6 inches deep.
18	do.....	2-2-4	2½	62.5	Do.
25	do.....	2-2-4	2	60.0	Do.
16	do.....	4-4-8	24	47.0	Seed in bulk, 5 feet deep; all not killed 6 inches deep.
15	Outside.....	4-4-8	24	34.0	Seed in bulk, 5 feet deep; none killed 2½ inches deep.
14	do.....	2-2-4	24	10.0	Seed in bulk, 4½ feet deep; all not killed 1 foot from floor.
12	Inside.....	2-2-4	48	.6	Seed in bulk, 5 feet deep.

POISONING EXPERIMENTS.

As a possible means of controlling the pink bollworm in the field, poison experiments were conducted in the laboratory with both adults and larvæ. Moths readily drink water in captivity when it is sprayed on the leaves or blotting paper in the breeding jars, and it was thought they might be killed by poisoning the drinking water with an arsenical solution. Repeated trials were made by using a solution of calcium arsenate for the moths to drink. The longevity of these moths was the same as that of those in the check, where pure water was used.

While the laboratory experiments in poisoning the adults were not encouraging, it was thought advisable to try it under field conditions. From the habit of the newly hatched larvæ of crawling over the plants and bolls before they enter, theoretically it seemed possible that a large number of young larvæ might be poisoned.

Average plats were selected at San Isidera, Tlahualilo, and at the laboratory for poisoning the plants. Weekly applications of powdered calcium arsenate were made with hand dusters. These applications were begun about July 15 and continued until the last week in October. The gauges on the machines were opened to their fullest extent and as heavy an application as possible was made each time. (Table XXVIII.)

TABLE XXVIII.—*Weekly examination of bolls from poison experiments: Average number of larvæ per boll.*

Week ending—	Tlahualilo.				San Isidra.		Lerdo.	
	Zaragosa.		Small experiment.		Poison.	Check.	Poison.	Check.
	Poison.	Check.	Poison.	Check.				
Aug. 2.....	0.05	0.13	0.6	0.66	0	0	0.62	0.62
Aug. 9.....	.11	.09	.6	.44	0	0	.80	.80
Aug. 16.....	.26	.23	.42	.46	.02	0	3.50	3.88
Aug. 23.....	.31	.38	.88	.32	.04	.05	4.34	3.14
Aug. 30.....	.57	.88	1.2	1.6	.02	.03	4.16	3.52
Sept. 6.....	1.2	.86	1.7	3.0	.14	.06	2.8	2.7
Sept. 13.....	1.8	5.10	2.3	2.6	.20	.10	4.6	4.8
Sept. 20.....	1.83	1.50	3.2	2.6	.25	.14	.....	.....
Sept. 27.....	1.45	5.10	1.2	1.1	.27	.28	6.28	5.84
Oct. 4.....	5.77	6.90	2.4	3.4	1.50	2.30	.....	.....
Oct. 11.....	6.40	8.40	4.0	4.5	3.70	3.0	.....	.....
Oct. 18.....	7.60	8.10	4.2	5.0	5.50	5.30	6.48	.....
Oct. 25.....	7.20	5.50	6.0	5.7	8.00	.....	.....	.....
Oct. 31.....	8.70	9.80	3.9	4.0	7.00	5.10	5.70	5.60

Weekly examinations of bolls both from the poisoned and check plats were made. The average number of larvæ per boll varied slightly. These variations, however, occurred in other samples of bolls where no poison was used and the poisoning did not check the infestation. The season of experiments was unfavorable for poisoning experiments. There was about twice the normal rainfall, which washed the poison from the plants, and, moreover, caused the cotton to grow so rank that it was impossible to get a thorough application with the available labor. Under more favorable conditions it is possible that better results might be obtained.

TRAPS.

TRAP LIGHTS.

In the laboratory, where the doors and windows were screened and the moths could not escape, they would frequently come to the electric lights, resting on the shade or wall near by, but under outdoor conditions moths would seldom come to lights. Acetylene and electric lights were suspended repeatedly in front of a white background in the laboratory cotton plats, where there were thousands of moths. In the course of 2 or 3 hours not more than 6 to 8 moths would come to the lights, while at the same time an examination with a flashlight would show there were large numbers on the plants only a few feet away. The few that did come to the lights were probably ones that we disturbed in moving about, and it can not be said there was any attraction whatsoever to the lights.

An electric trap light was also placed within a few feet of the plants, with negative results. Another trap light was run all night for 15 consecutive nights in an open shed where there were hundreds of tons of seeds and only 5 moths were taken. During the same 15 nights

large numbers of moths were emerging from material at the laboratory which had been taken from this same shed a few weeks before, and it is certain that large numbers of moths were emerging in the seed shed while the trap was in operation. Light traps have been recommended as a means of control by several people. Gough (12), Willcocks (7), Ballou (11), and others report catches of thousands of moths per night in light traps. Ballou (11) found that most of the moths came to the light in the hour following sunset. Some authors found lights so attractive to the moths that they were used to determine the number of moths emerging from stored material, but in Mexico we found that practically none came to the lights. Busck (8) in Hawaii also found that the pink bollworm moths were not attracted to lights.

ATTRACTION TO FRUIT.

Cone-shaped traps of the type used for flies were baited with oranges, bananas, apples, mangoes, guavas, and pineapples and were repeatedly exposed among the cotton plants with absolutely negative results.

RECOMMENDATIONS FOR CONTROL.

Too much can not be said and done in encouraging the destruction of hibernating larvæ. They are the source of infestation for the following year. If 9 per cent or less of the larvæ are able to survive the natural mortality of winter and early spring in irrigated fields, this small percentage, with the larvæ surviving in the seed and other places, produces an infestation the following year that causes approximately 25 per cent gross loss to the Laguna crop. Every hibernating larva killed during the winter or early spring before oviposition begins means the cutting off of many thousand larvæ by the end of the season. The paramount necessity, then, is to reduce the survival of hibernating larvæ to as low a figure as possible.

BURNING OF OLD STALKS AND BOLLS.

Just as soon as possible the stalks should be cut and raked up in piles. Old bolls, sticks, and trash of all descriptions to which larvæ may be attached should be carefully picked up and burned with the stalks, the main object being to burn everything in the field that contains larvæ or would be likely to afford protection for hibernating larvæ. If possible, the cutting and piling of the stalks should be done while the plants are still green, in this way minimizing the labor and increasing the effectiveness of the operation. Green stalks will retain most of their bolls, which shatter when they are cut dry. Just as soon as the piles lose their green color and become more or less dry they should be burned. Better results can be gained by waiting for this drying to take place rather than by burning the plants while they are yet green. Ordinarily the old stalks are cut and burned in

the Laguna when preparing the land for the new crop. While this is done for purely agricultural reasons to make plowing easier, large numbers of live hibernating larvæ are killed. On the experimental plot at Lerdo the stalks were cut on the last day of February and examined during March. At this examination live larvæ at the rate of over 5,000 per acre were found in the bolls attached to the stalks. So many bolls had fallen or were knocked off during the cutting and piling that over half were left on the ground. A little extra effort in collecting and destroying these is well worth while. No boll or piece of cotton is so small or negligible that it should not be picked up and burned.

CUTTING STALKS AND FALL PLOWING.

Experiments have shown conclusively that the mortality is greater in hibernating larvæ buried in the soil than in those left on top of the soil and greater in those buried in irrigated soil than in those buried in dry soil. It has also been found that the most favorable of all places for larvæ to hibernate under field conditions are the old bolls left undisturbed on standing stalks. During the winter of 1919-20 100 larvæ per 100 bolls successfully passed the winter on old stalks left standing in the fields and were alive on July 12, whereas only 4 larvæ per 100 bolls were found alive on this date in bolls lying on top of the soil. These facts suggest certain agricultural practices that can be used to good advantage in reducing the number of surviving larvæ.

Ordinarily the old stalks are not left standing in the fields, but on some plantations large acreages which are not to be cultivated the following year are left, and on others where "zoca" is produced the stalks are not cut till late spring or summer. All fields should be gone over with a stalk-cutter as early as possible, and in many cases the small amounts of cotton which are picked during the winter and spring could profitably be sacrificed in order to do this earlier in the season. Fall and winter plowing to cover the bolls is recommended whenever it is possible, and water should be applied in years when there is an excess.

PASTURING.

If it is not possible to cut and burn the stalks or plow the field in the above manner, owing to labor shortage, weather conditions, or other causes, it is a very good idea to graze the fields. Cattle, goats, and burros will eat the majority of the bolls on the stalks. One important drawback to the grazing plan is that there is a certain amount of infested material tramped into the ground. In one field near the town of Tlahualilo where the animals had been concentrated, only about one boll per square yard was found on the ground. In other fields that had been grazed, but not so thoroughly, an average of 5 or 6 bolls per square yard was found.

CLEANING GINS, OIL MILLS, AND SEED WAREHOUSES.

In Mexico, where the infestation grows to be very intensive, thousands of live larvæ have been observed to come from the cleaners with the trash. It is the common practice there merely to collect this trash containing the large number of worms and place it in piles. The "cleanings" should be caught in a receptacle rather than allowed to fall on the ground, because the larvæ will crawl and secrete themselves in cracks, crevices, and rubbish of various kinds. This trash should be either burned or subjected to some treatment insuring the death of the insects contained therein. If the trash does not contain too much dirt to make it unburnable, the best plan is to burn it in the boilers. A very good plan was devised by Mr. T. M. Fairbairn for handling the unburnable material. The end was knocked out of an oil barrel and a small steam line run into the barrel, almost to the bottom. The trash from the cleaners fell into the steaming barrel and all larvæ were quickly killed.

After the season is over the gin plant or oil mill should be thoroughly cleaned. All seed and rubbish should be removed from every nook and crevice of the machinery and buildings and burned. If the structure of the buildings permits they should also be fumigated after cleaning.

It is the usual custom to keep enough seed on the plantations for a second planting in case it is necessary. This seed should be as carefully fumigated as the seed that is planted, and as an additional precaution should be stored in a moth-proof screened room. It was very noticeable that the infestation always began earlier in the season and was heavier in the fields nearest the gins and seed warehouses.

FUMIGATION.

All seed used for planting or kept on the plantation after the first of March should be fumigated. An air-tight room is necessary for a successful fumigation, and it is better to build a special fumigation house at least a hundred yards from the other buildings, so that there will be no danger from fire. Carbon bisulphid is highly inflammable, and no fire should be allowed around the house while fumigation is being done. The ordinary adobe construction is satisfactory, but precautions should be taken to see that plenty of mud is used and all cracks between the adobes well filled. A brick floor set in mortar should be provided and the inside plastered. The plastering not only makes the building more air-tight, but prevents absorption of the gases by the walls. The doors should be of matched wood, and paper should be plastered over the cracks when closed. Seed may be fumigated in sacks or in bulk, but in either case should be packed as little as possible. In no case should the seed to be fumigated be over 5 feet deep. One pound of carbon disulphid should be used

for every 80 cubic feet. The entire area of the building should be calculated and not the space occupied by the seed only. As it costs as much to fumigate the air space as it does the seed, it is more economical to make the room only high enough for a person to stand comfortably. The size of the building needed can be calculated from the tons of seed to be fumigated, a ton of seed occupying 85 cubic feet ($2\frac{1}{2}$ cubic meters).

All water should be separated from the carbon disulphid and after the seed is in the house the disulphid poured into shallow vessels placed on top of the seed. Not more than a pound should be placed in each vessel, so that it will evaporate quickly. Old gasoline cans cut down to about 3 inches high, or earthenware bowls, make good containers. The vessels should be scattered over the top of the seed pile and the disulphid poured into those farthest from the door first. There is no danger in doing this, but it is more convenient to have a number of half-inch pipes fitted with caps or corks extending through the walls and introduce the disulphid from the outside. As soon as the liquid is poured into the vessels the door should be closed and paper stuck over the cracks with flour paste. The house should be kept closed for at least 24 hours, and longer will do no harm, as continued exposure to the gas does not injure the germination of the seed.

PLANTING EARLY VARIETIES.

From the life history and feeding habits of the pink bollworm it can be readily seen that the later the cotton crop is in maturing the greater will be the amount of loss. Every cultural practice should be used in securing as early maturity as possible of the available cotton varieties.

SUMMARY.

The pink bollworm was introduced into Mexico in 1911 with seed for planting. Five years later it was generally and uniformly distributed throughout the Laguna and had reached its maximum development.

Infestation is started in the spring as soon as squares are formed, by moths emerging from hibernating larvæ, and rapidly increases until practically every boll is infested with several larvæ by fall.

The life cycle is completed in an average of 31 days in the summer, but the larval stage of hibernating or resting larvæ may be extended for 2 years or more.

Dispersal is mainly through the carriage by man of hibernating larvæ in seed, but local dispersion is brought about also by flight and carriage of adults.

The pink bollworm causes approximately 25 per cent gross damage to the Laguna crop by feeding in the bolls and squares. This feeding results in a reduction in the quantity and quality of the lint pro-

duced, reduction in the quantity of seed, and lowering of the quantity and quality of the oil content of the seed.

Early cleaning of fields by burning all the old stalks and bolls, cleaning and fumigation of gins, oil mills, and seed warehouses, the fumigation of all seed kept on the plantations, and the early maturity of the crop are recommended as means of control.

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APPENDIX.

The following generic and specific description is reprinted from "The pink bollworm, *Pectinophora gossypiella*," by August Busck, Journal of Agricultural Research, vol. 9, no. 10, Washington, D. C., June 4, 1917.

HOW TO DISTINGUISH THE PINK BOLLWORM IN THE FIELD.

Definite and final determination of *P. gossypiella* in any stage can be made only by the aid of the microscope; and, unless a collector or inspector is thoroughly familiar with the species, all suspected material should be sent at once to the Bureau of Entomology for determination. Even a fraction of the insect in any of its stages can be recognized under the microscope by the characters given in succeeding sections of this paper.

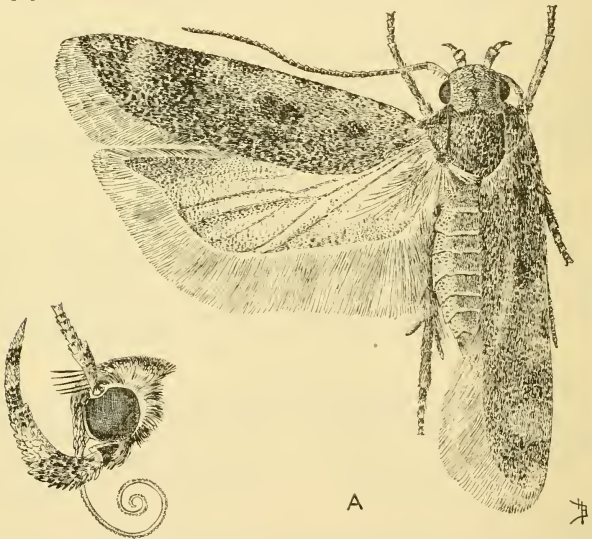


FIG. 4.—Pink bollworm: Adult. (Busck.)

The following essential characters, all of which can be discerned by the aid of a common pocket lens, will enable the practical worker to make a reasonably certain preliminary determination of the insect in all its stages in the field.

If a small dark-brown moth is caught in the cotton field or in a cotton mill or warehouse and is found to have the forewings pointed and the hindwings broad and sinuated below the tip and to possess long curved palpi and long stiff hairs on the first antennal joint, it is reasonably certain that the moth is *P. gossypiella*, the adult of the pink bollworm (fig. 4, A).

If, within the cotton boll or associated with stored cottonseed, a small white or pinkish caterpillar with brown head is found and under a hand lens the mandibles are

seen to have four teeth (fig. 5, *A-D*) and the crotches on the abdominal prolegs form a partial circle or horseshoe, opening outwards (fig. 5, *H*), the caterpillar will most probably prove to be the pink bollworm.

Again, if, within a cotton boll or otherwise associated with cotton in the field or in the mill, a small lepidopterous pupa is found, which under the lens is found to be entirely covered with a short velvety pubescence and to possess a short, curved, up-turned hook at the posterior end (fig. 6, *A-D*), it may with considerable certainty be determined as a pupa of the pink bollworm.

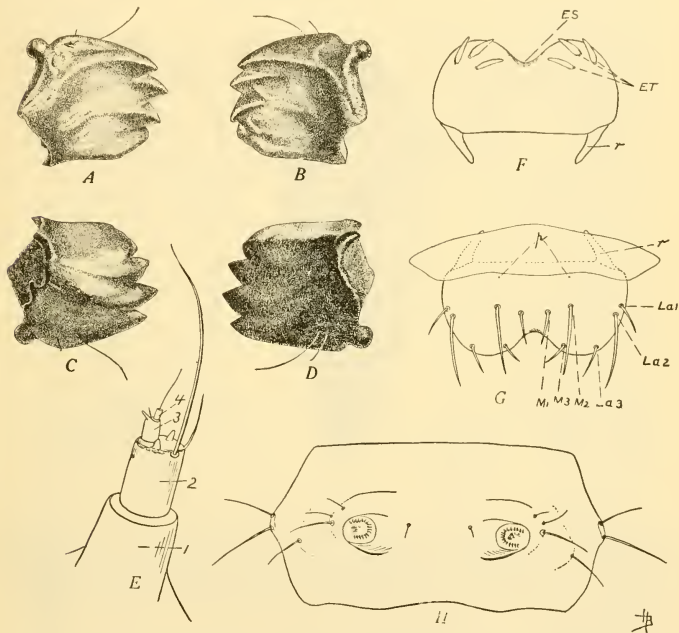


FIG. 5.—Pink bollworm: *A*, Right mandible of larva from underside. *B*, Left mandible from underside. *C*, Right mandible from upper side. *D*, Left mandible from upper side. *E*, Left antenna of larva from underside: 1, First joint; 2, second joint; 3, third joint; 4, fourth joint. *F*, Epipharynx of larva: *ES*, Epipharyngeal shield; *ET*, epipharyngeal seta; *r*, epipharyngeal rod. *G*, Labrum of larva: *La*₁, Lateral labral seta 1; *La*₂, lateral labral seta 2; *La*₃, lateral labral seta 3; *M*₁, median labral seta 1; *M*₂, median labral seta 2; *M*₃, median labral seta 3; *p*, labral punctures; *r*, epipharyngeal rod. *H*, Underside of third abdominal segment of larva. (Busck.)

GENERIC DESCRIPTION.

Pectinophora, new genus (Gelechiidæ).

Type: *Gelechia gossypiella* Saunders.

MOTH.—Face and head smooth. Labial palpi long, recurved, reaching above vertex; second joint thickened on the underside with slightly furrowed brush, which is evenly attenuated toward apex; terminal joint shorter than second, somewhat thickened with scales in front, compressed, pointed. Maxillary palpi minute, deflected. Tongue long, spiraled, scaled in its entire length. Antennæ serrated and finely ciliated on the underside; basal joint with heavy but sparse (5-6) pecten. Thorax smooth. Forewings (fig. 7, *A*) elongate ovate, pointed, smooth; 12 veins, 7 and 8

stalked to costa, rest separate, 1b furcate at base.⁶ Hindwings (fig. 7, *B*) somewhat broader than forewings, trapezoidal; costa deflected from the middle; apex pointed; termen sinuate; 8 veins; 8 connected with cell by an oblique bar; 6 and 7 closely approximate at base; 3 and 4 connate; 5 parallel with 4; frenulum simple in the males, triple in the females. Male genitalia (fig. 9, *B*), with harpes and uncus well developed; tegumen evenly chitinated. Posterior tibiae (fig. 9, *A*) hairy above.

LARVA.—Head (Pl. V and fig. 8) spherical, nearly circular in outline viewed from above, a little wider than long; greatest width a little behind the middle; incision of dorsal hind margin about one-fourth of the diameter of the head; distance between

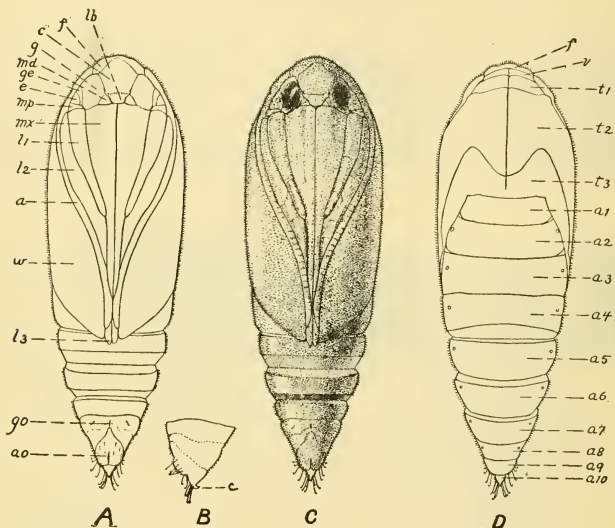


FIG. 6.—Pink bollworm. *A*, Pupa from front: *lb*, Labrum; *f*, front; *c*, clypeus; *g*, gena; *md*, mandibles; *ge*, glaced eye; *e*, eye; *mp*, maxillary palpus; *mx*, maxilla; *h*, first thoracic leg; *l*₂, second thoracic leg; *l*₃, third thoracic leg; *a*, antenna; *w*, forewing; *go*, genital opening; *ao*, anal opening. *B*, Tip of pupa from left side; *c*, Cremaster. *C*, Mature pupa, with eyes of the imago visible through pupal skin. *D*, Pupa from back: *f*, Front; *v*, vertex; *t*₁, first thoracic segment; *t*₂, second thoracic segment; *t*₃, third thoracic segment; *a*₁, first abdominal segment; *a*₂, second abdominal segment; *a*₃, third abdominal segment; *a*₄, fourth abdominal segment; *a*₅, fifth abdominal segment; *a*₆, sixth abdominal segment; *a*₇, seventh abdominal segment; *a*₈, eighth abdominal segment; *a*₉, ninth abdominal segment; *a*₁₀, tenth abdominal segment. (Busck.)

dorsal extremities of hind margin about one-half of the width of the head. Front triangular, reaching beyond the middle; adfrontal sutures somewhat undulating, reaching to the incision of hind margin; adfrontal ridges converging from near the middle, at the point of attachment of tentorial arms, to the longitudinal ridge, which is one-half as long as front. Projection of the dorsal margin over the ventral is one-half of the diameter of the head. Triangular plates of hypostoma distinctly separated by a slightly pigmented gula, nearly equilateral, but somewhat elongated and projecting slightly beyond the ventral margin of epicranium.

Ocelli six; i, ii, v, and vi forming a parallelogram; iii and iv on a line between ii and v; v smaller than the rest.⁷ Epistoma with the usual two pairs of setae (*E*₁, *E*₂) well developed.

⁶ The European (*Gelechia*) *Pectinophora malvella* Zeller exhibits an amount of variation of the venation in the forewing which is very unusual in this group of insects. Veins 2 and 3 in this species are sometimes coincident or partly coincident at base or at tip; the variations sometimes differing in the two wings of the same insect. No such variation has been ascertained in *P. gossypiella*, where the venation seems constant, as given above.

⁷ This numbering of the eyes differs from that of Fracker in that his numbers 5 and 6 are reversed, so as to make them continuous with the rest. (Fracker, S. B. The Classification of Lepidopterous Larvae . . . 169 p., 10 pl. Urbana, Ill., 1915. Bibliography, p. 145-146. Illinois Biological Monographs, v. 2, no. 1.)

Frontal punctures (Fa) close together, anterior to frontal setae (F_1); distance between punctures less than distance between puncture (Fa) and setae (F_1); frontal setae (F_1) and adfrontal setae (Adf_1 and Adf_2) nearly equidistant; second adfrontal seta (Adf_2) approximate to but before beginning of longitudinal ridge (LR); adfrontal puncture ($Adfa$) midway between adfrontal setae.

Epicranium with normal number of primary setae, 13, and punctures, 7, and with three small ultraposterior punctures⁸ (x, y, and z).⁹

Anterior setae¹⁰ (A_1 , A_2 , A_3) in a slightly obtuse angle; A_1 and A_2 closer together than A_2 and A_3 ; anterior puncture (Aa) between A_1 and A_2 . Posterior setae¹¹ (P_1 , P_2) and posterior punctures (Pa, Pb) near the middle of the head; P_1 on the level with

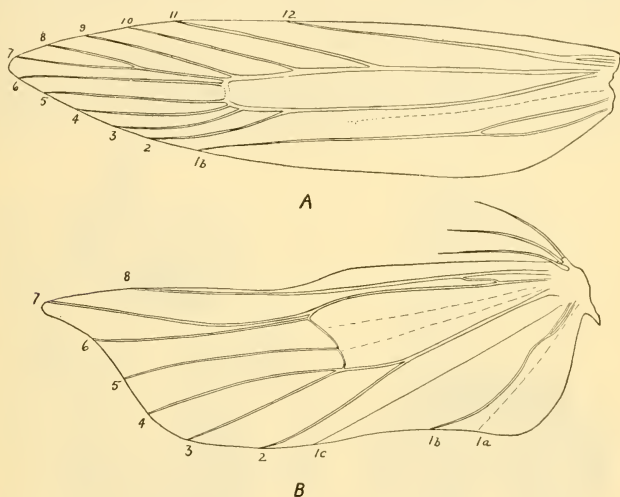


FIG. 7.—Pink bollworm: A, Venation of forewing; B, venation of hindwing. (Busck.)

adfrontal puncture¹²; P_2 posterior to Adf_2 . Pa equidistant from P_1 , A_3 and the lateral seta (L_1) remote from the anterior group, nearly on the level with P_1 ; lateral seta (L_1) remote from A_3 , nearly on the level of Pb; lateral puncture (La) posteroventral to the seta, remote. Of the ocellar setae (O_1 , O_2 , O_3),¹³ O_1 is equidistant from and lateral to ocelli ii and iii, O_2 is closely approximate and posteroventral to ocellus i; O_3 is directly ventral and remote from O_2 , on a line with ocelli v and vi; ocellar puncture (Oa) between O_3 and ocellus vi, approximate to latter. Subocellar setae (So_1 , So_2 , So_3) triangularly placed, nearly equidistant; subocellar puncture (Soa) between and equidistant from So_2 and So_3 . Genal seta (G_1) and puncture (Ga) both present; puncture anterior to seta.

Labrum (fig. 5, F, G) with median incision rather deep and evenly rounded. The three lateral setae (La_1 , La_2 , La_3) close to edge, La_1 and La_2 closely approximate, La_3 remote; median setae (M_1 , M_2 , M_3) in the usual Micro arrangement with M_2 lateral and slightly posterior to M_1 ; M_3 close to anterior margin on a line with La_3 ; M_1 and M_2 on a line respectively with La_2 and La_1 .

⁸The nomenclature of the head setae has been adopted from Heinrich [Heinrich, Carl. On the taxonomic value of some larval characters in the Lepidoptera. In Proc. Ent. Soc. Wash., v. 18, no. 3, p. 154-164, illus. 1916.] with certain minor modifications, noted in the following footnotes and concurred in by Mr. Heinrich.

⁹So-called "secondary punctures" of Heinrich, sometimes bearing minute setae.

¹⁰Anterodorsal setae of Heinrich.

¹¹Posterodorsal setae of Heinrich.

¹²The term "on the level with" is used in these descriptions as the head setae are seen in frontal projection (Pl. V, A); anything above a level is termed "posterior" and anything below is termed "anterior."

¹³Heinrich's numbering reversed.

Epipharyngeal shield (ES) merely a slight chitinization of the edge of the median incision; epipharyngeal setae narrow plates, triangularly grouped near anterior margin. Epipharyngeal rods not discernible in the labrum proper, only represented by their posterior projections, which are rather well developed.

Mandibles (fig. 5, *A-D*) strong, as broad as long, with four stout, rather short teeth; the three lower ones pointed; the upper blunt; a fifth lower tooth is slightly indicated on the underside; one long and one shorter seta on upper side near lower edge.

Labium and maxillae normal (fig. 8, *C*).

Antennae (fig. 5, *E*) four-jointed, with second joint considerably longer than joint 3, longer than broad; the longer seta longer than the entire antenna; papillae minute, much shorter than third joint.

Three pairs of normal thoracic feet; four pairs of abdominal prolegs with crotches of uniform size in an incomplete circle, opening outwardly (fig. 5, *H*); anal prolegs with a transverse row of uniordinal hooks.

The arrangement of the body setae is normal, as shown in figure 10, *A, B*. It differs from that of *Gelechia* in having the three setae on prespiracular plate of prothorax nearly equidistant, while in *Gelechia* the posterior seta is farther separated from the two others than they are from each other, and in having the three setae vii of the proleg-bearing abdominal segments arranged in a triangle, not in a line as in *Gelechia*.

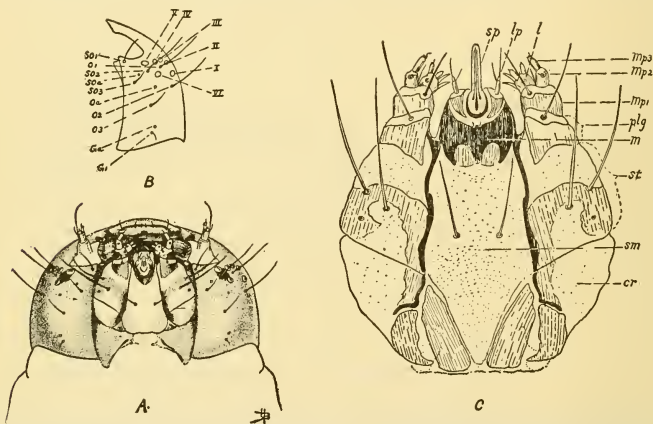


FIG. 8.—Pink bollworm. A, larval head from underside. B, Seta arrangement of epicranium in figure A: I, Ocellus i; II, ocellus ii; III, ocellus iii; IV, ocellus iv; V, ocellus v; VI, ocellus vi; O₁, ocellar seta 1; O₂, ocellar seta 2; O₃, ocellar seta 3; O_a, ocellar puncture; SO₁, subocellar seta 1; SO₂, subocellar seta 2; SO₃, subocellar seta 3; SO_a, subocellar puncture; G₁, genal seta; G_a, genal puncture. C, Labium and maxilla: sp, Spinneret; lp, labial palpus; l, lacinia and galea; m, mentum; sm, submentum; cr, cardo; st, stripes; plg, palpiger; mp₁, maxillary palpus, first joint; mp₂, maxillary palpus, second joint; mp₃, maxillary palpus, third joint. (Busck.)

The genus differs further from *Gelechia* in the possession of an antennal pecten in the moth, and in the arrangement of the setae of the larval head; A₁ is anterior to A₂, not posterior to it as in *Gelechia*; P₁ and P₂ are posterior, respectively, to Adf₁ and Adf₂, which in *Gelechia* are nearly opposite to these, and L₁ is posterior to P₁, not on the level with it as in *Gelechia*.

The most striking larval difference is in the crotches of the abdominal prolegs, which are uniordinal and arranged in an incomplete circle, broken outwardly (fig. 5, *K*). In *Gelechia* they are biordinal and in a complete circle.

PUPA.—The pupa of *Pectinophora gossypiella* is pubescent, without any long setae except on last joint, and thus is easily distinguished from the smooth, seta-bearing pupa of *Gelechia*; cremaster present.

SPECIFIC DESCRIPTION.

MOTH (fig. 4, *A*).—Labial palpi reddish brown; second joint with two diffused black bars exteriorly; terminal joint with two well-defined, broad, black annulations, one at base, the other at apical fourth. Antennae brown with narrow black annulations;

basal joint with long black pecten. Face and head light reddish brown with some pale iridescent scales. Thorax reddish brown with a sprinkling of black around the collar; patagia somewhat lighter brown, unmottled. Forewings darker brown with a series of small, ill-defined, black spots along the costal edge from base to apical fourth, where there is a larger dash of light ochereous brown; dorsal edge and apical part of wing suffused with darker, blackish brown; the middle of the wing is irregularly sprinkled with blackish scales and contains on the cell an ill-defined, round, blackish spot, sometimes divided into an upper and lower spot; there is also a smaller spot on the base of the cell; the pattern of the wing is rather vague and there is considerable variation in different specimens; in many there is an ill-defined blackish fascia at apical fourth just before the light costal dash, but in other specimens this fascia is not present and the round dorsal spot is dissolved into several smaller spots. Cilia

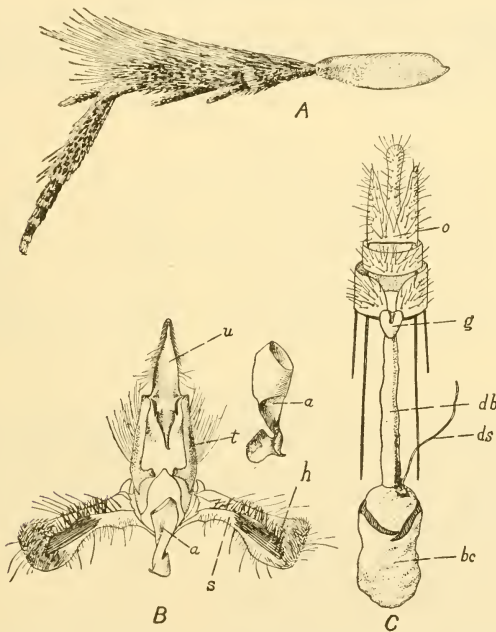


FIG. 9.—Pink bollworm: *A*, right hind leg. *B*, genitalia of male: *u*, Uncus; *t*, tegumen; *h*, harpe; *a*, aedeagus; *s*, sacculus. *C*, genitalia of female: *o*, Ovipositor; *g*, genital plate with genital opening; *db*, ductus bursae; *ds*, ductus seminalis; *bc*, bursa copulatrix. (Busck.)

light ochereous brown, streaked with blackish. Hindwings dark fuscous, somewhat iridescent, lightest toward base; cilia ochereous, terminal and apical parts suffused with dark fuscous; vein 1c with long, ochereous fuscous hairs on the upper side. Abdomen flattened and ochereous above, dark brown laterally with underside suffused with black and with ochereous scaling at the joints. Legs (fig. 9, *A*) blackish fuscous with narrow ochereous annulations at the joints. The abdomen is very similarly shaped in the male and in the female and it is exceedingly difficult to distinguish the sexes, even in living moths, without dissection or by examination of the frenulum. The male genitalia (fig. 9, *B*) are remarkably small in proportion to the size of the species: harpes narrow at base, broadening towards tip; tip strongly haired; a cluster of long, heavy, straight spines from inner side, well within the tip; sacculus armed on its edge with a row of stout spines; uncus moderately long, broad at base, tapering to a point, laterally heavily haired; aedeagus short, stout, with a terminal hook. In the female the ovipositor is weakly chitinized, covered with stiff hairs;

genital plate heart shaped; bursa copulatrix with two opposite, strongly chitinized, hornlike, serrated invaginations (fig. 9, C).

Alar expanse 15 to 20 mm.

FULL-GROWN LARVA.—The full-grown larva (fig. 10, A) is 11 to 13 mm. long, cylindrical, white, with dorsal side strongly suffused with pink. Head reddish brown with blackish brown mandibles and the other trophi yellowish. Thoracic shield rather small, divided in the middle, dark brown. [On each side of the thoracic shield is a small, slightly depressed, kidney-shaped spot, thinly chitinized and less pigmented than the rest of the shield. This purely specific character is easy to observe and may be of some assistance as contributory evidence in a preliminary determination of the pink bollworm in the field (fig. 11).] Anal plate small, dark brown.

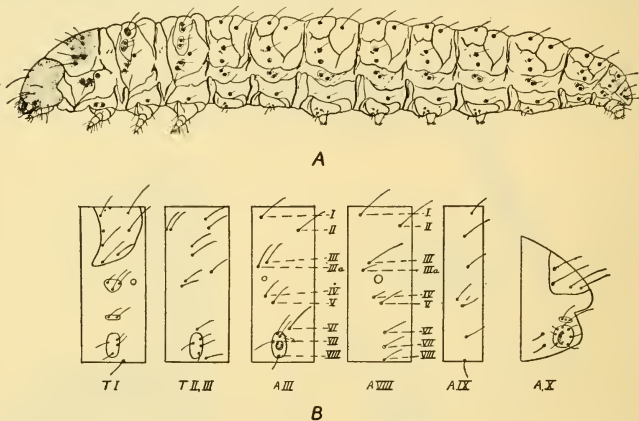


FIG. 10.—Pink bollworm: A, larva. B, schematic chart of arrangement of body setae of larva. T I, first thoracic segment; T II, III, second and third thoracic segments; A III, third abdominal segment; A VIII, eighth abdominal segment; A IX, ninth abdominal segment; A X, tenth abdominal segment. (Busek.)

Tubercles small, but distinct, yellowish brown, surrounded by deeper pink than the prevalent suffusion and bearing rather short, dark-brown setae. Crotches of abdominal feet 15 to 17.

PUPA.—The pupa (fig. 6, A-D) is 8 to 10 mm. long, rather plump, reddish brown; posterior end pointed and terminating in a short, stout, upwardly turned hooklike cremaster; entire surface finely pubescent; no long setae, spines or hooks, except on last joint; fronto-clypeal suture distinct and curved sharply upward; clypeus, labrum, pupal eyes and mandibles distinctly indicated; antennae diverging at their extreme tip and not reaching to the tips of the wings; metathoracic legs reaching slightly beyond the wings to fifth abdominal segment. Spiracles small, normal. Anal opening large, slitlike, surrounded by strong hooked setae, 5 or 6 on each side; cremaster surrounded with 6 to 8 similar, strong, hooked setae. Genital opening slitlike, single in both sexes. When mature, the pupa becomes much darker (fig. 6, C); the imago's eyes can be seen prominently under the gena of the pupal skin, and the segmentation of the adult antennae and legs becomes discernible.

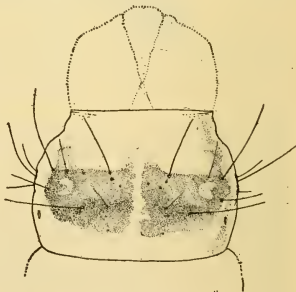


FIG. 11.—Thoracic shield of pink bollworm larva. (Original.)



CLOVER-LEAF WEEVIL.

By

D. G. TOWER and F. A. FENTON,

Cereal and Forage Crop Insect Investigations.

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INTRODUCTORY.

The clover-leaf weevil, *Hypera punctata* Fab. (fig. 1), ranks as one of the important clover pests. Although it is usually unnoticed, it annually exacts its toll of the crop. It seldom devastates entire fields, however, because the larvæ are ordinarily checked by an ever-present fungous disease which spreads rapidly and reduces their numbers to a negligible quantity in a remarkably short time.

DISTRIBUTION.

This insect was introduced accidentally into this country from Europe, where it is well known. It also occurs in northern Asia and probably in central Asia and China. So far as known it is the only species of *Hypera* that has reached this country, the genus being indigenous to the eastern hemisphere.

The first record of *Hypera punctata* occurring as a pest in the United States was in 1881 when a severe outbreak occurred at Barington, N. Y. A single specimen taken about 1850-1855 in Canada by the Geological Survey and identified by Dr. LeConte in 1876 shows that this species had been in America for some time before becoming noticeable or seriously injurious.

In 1882 Lintner took a specimen in Vermont. In 1884 *punctatus* reached Canada in numbers, flying across the lake from Buffalo to Ridgeway, 1889 it occurred in several places in Ohio * * * and Schwarz identified a beetle taken from the stomach of a crow killed in Michigan in 1892 as this species. Southward by 1890 it had spread over New Jersey and reached Philadelphia, where it was very common. The year 1894 gave records from Maryland, West Virginia (Hopkins), and Indiana * * * Folsom records its first appearance at Urbana as 1903 * * * R. L. Webster reported it from Iowa in 1910. On the west coast Hanhem reported it from Vancouver in 1902

(Fletcher) and in 1906 E. S. Wilmot states that it was up the Fraser River as far as Harrison's, about 20 miles from the south line of British Columbia. (Titus 7, p. 405-406).¹

It is now found in the additional States of Delaware, Idaho, Kansas, Kentucky, Maine, Massachusetts, Mississippi, Missouri, Nebraska, New Hampshire, North Carolina, Oregon, Rhode Island, Tennessee, Texas, Utah, Virginia, Washington, and Wisconsin.

DESCRIPTION.

The descriptions are taken almost entirely from Titus (7, p. 402-404), with additions by the authors inclosed in brackets.

Adult [fig. 2]: Length 5 to 10 mm. Width 3 to 5.7 mm.



FIG. 1.—Adults of the clover-leaf weevil feeding.

Stout, black or brownish black. Clothed with blackish brown pale brown, yellow-brown or gray scales which are short broad and emarginate at the tips, and with short erect bristles, edge of elytra yellow brown or at least paler than remainder of scales.

Head clothed with short metallic yellowish scales; *front* not as wide as breadth of eye, densely clothed with dark yellow hairs or scales which extend over two-thirds of the beak; *eyes* elongate oval, narrowed beneath, rather prominent; *beak* scarcely two-thirds the length of the prothorax, and one-half thicker at tip than width of front, beneath on the sides and near the tip polished and densely punctate; an elongate impression on dorsal surface above the antennal groove; antennal groove black,

¹ Reference is made by number (italic) to "Literature Cited," p. 18.

deep, punctured; *antennæ* reddish-black, scape reaching to middle of eyes, not as long as funicle, not greatly enlarged at tip; first joint of funicle distinctly longer than second, enlarged at the apex so that it is about one-half as thick as long, second joint equal to three and four united, joints three to seven regularly shorter and broader, seven as wide as long, club elongate-oval, pointed at the tip, *antennæ* with many fine hairs, those on club very fine and dense. Mandibles polished, dull red, not emarginate at tip, maxillæ and all the palpi pale brownish-red.

Prothorax broader than long, broader in female than in male, in the female broadly widened in front of the middle, in the male converging more behind than in female; sides broadly impressed, only slightly swollen; *dorsum* densely rather coarsely punctured, densely clothed with scales and with many slender pointed hairs; usually with a narrow pale median dorsal line bordered with wide dark, almost black in some, bands of scales which reach to the sides; sides and beneath with dark yellow scales, generally with a dark spot on sides behind and an indistinct dark line running from this spot toward the front.

Scutellum extremely small, narrowly triangular, clothed with pale scales.

Elytra very broad, at tip broadly rounded, sides especially in the male nearly parallel, humeri prominent and clothed with darker scales. Suture and alternate interspaces more strongly elevated than others, deeply striately punctured, *striæ* without *setæ*; each interspace with a single row of black *setæ* pointing backward and partially decumbent, more erect behind; tip of *elytra* and often the sides with some short white hairs. The coloration of the scales varies from solid gray to black, through various shades of brown yellows. Some specimens are tessellated with brownish-yellow and black, the tessellation usually on the more elevated interspaces.

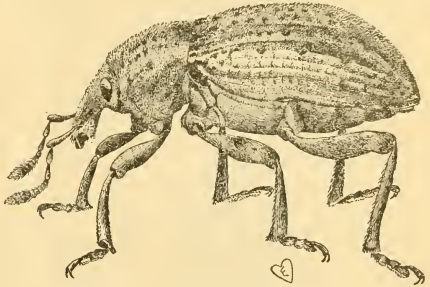


FIG. 2.—Adult clover-leaf weevil, lateral view. Much enlarged.

In the male the outer interspaces have paler scales even in the darkest specimens, in the female this pale coloration is sometimes, but rarely, entirely absent.

Venter with lighter colored scales and many light hairs; front *coxæ* slightly separated, mesosternal process between middle *coxæ* broad perpendicular, triangular at tip; intercoxal process of first abdominal segment very broad, *coxæ* separated by more than their width. First segment in male impressed, emarginate posteriorly. Stem of male genitalia nearly or quite as broad as long.

Legs short, stout, especially the femora; black, tarsi often ferruginous, claws long curved, red and darker at tips; front tibiæ and hind femora distinctly curved, front tibiæ more so in male; legs usually clothed with lighter scales and hairs than the body, femora scaled, tibiæ and tarsi sparsely haired; middle tibiæ with a distinct apical hook.

Egg [fig. 3]: Elongate oval, 1.1 mm. to 1.2 mm. long, 0.5 to 0.6 mm. broad, very regularly hexagonally sculptured * * *. [Watery yellow when laid, with a smooth shining shell, the yellow color deepening with age to pale olive green and finally turning to a dull black.]

Larvæ [2] (Descriptions from Riley, Folsom, and observations by the author). *First stage*: 1.5 to 2 mm. long, narrow, thickest at middle, tapering toward both ends;

² The head widths for the different larval instars are quite constant and the averages will be found in Table I.

head brown, blackish-brown or black, with many fine transverse lines on the face; eyes very small, circular, projecting; mandibles terminating in two large sharp teeth, more or less separated, the lower one again divided into two or three parts; palpi pale yellow, mandibles brown or dark brown; dorsum of first thoracic segment with a rectangular dark band interrupted by a paler dorsal line which is the continuation of the stem of an inverted Y on the face, this dorsal band becomes wider on the abdominal segments and extends to the tip of anal segment. Hairs on the tubercles clavate as in several other species. [The color varies from the usual pale green to a bluish green or yellow when hatched. Yellow larvæ may retain this color throughout development.]

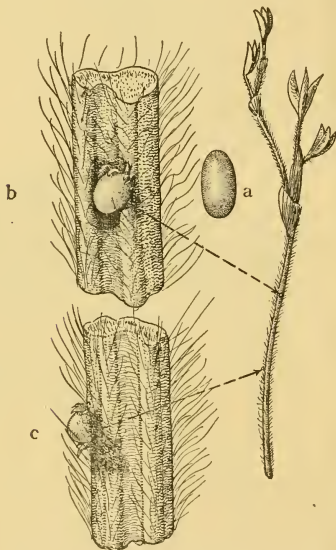


FIG. 3.—Egg of the clover-leaf weevil: a, Lateral view; b, egg inserted into stem of clover plant; c, lateral view of b. Much enlarged.

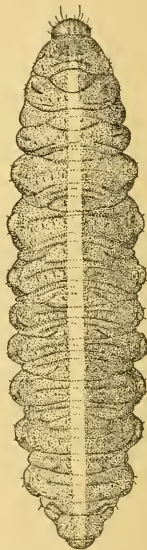


FIG. 4.—Full - grown larva of the clover-leaf weevil, dorsal view. Much enlarged.

Second stage: Color greener, head dark brown, front and sides of rectangular plate on first thoracic segment dark, the remainder greenish; dorsal median line with a fine dark border, darker than the remainder of the larva. Side line below spiracles indistinct. Length 4-4.5 mm., width 2 mm.

Third stage: Black lines on each side of dorsal line very distinct [head brown or yellowish brown], eyes densely black, antennæ darker. Color of larvæ (Folsom) may be blue green [yellow, or with a pinkish tinge]. Usual color pale green. Length 5 to 7 mm., width 2.5 to 3 mm. in the middle.

Fourth stage [fig. 4]: Dorsal line very white or pinkish, bordered by rose color, usually rather pale but sometimes rosy-black, the outer borders of this coloration are black and form distinct lines, interrupted on the margin of each segment [head brown or yellowish brown]; larva much darker green [or still may retain its yellow, blue green, or pink color]; lines below the spiracles dark both showing a tendency to

be brown or blackish [posterior segments yellowish]; the surface of the body much rougher in this stage than in others, the triangular points of the cuticle standing out prominently; tubercles [fig. 5] on thoracic segments below very strong and the hairs more prominent than in earlier stages. Length 8 to 14 mm.

Cocoon [fig. 6]: * * * Oval, 9-10 mm. long and 6.5 to 7 mm. wide. [A fine network of coarse threads which are light straw color when spun and brown after aging.]

Pupa: When first formed with yellow-green head [lighter colored antennæ, legs and wing-pads] * * *. Abdomen dark green with a distinct pale dorsal line that extends onto prothorax * * *. Frontal row of hairs rather distant from margin; central pairs close together, three following pairs form a curved line ending near the posterior outer edge; a few hairs on remainder of thorax; transverse rows of blunt setæ on each dorsal abdominal segment;

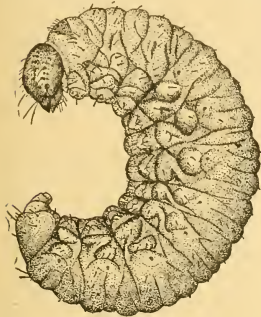


FIG. 5.—Full-grown larva of the clover-leaf weevil, lateral view. Much enlarged.

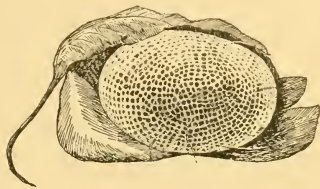


FIG. 6.—Cocoon of the clover-leaf weevil surrounded by leaves of clover plant. Enlarged.

hairs on beak rather short and thin; those on anal segment moderately long, stout and dark. [The pigmentation of the eyes, mandibles, and leg joints occurs at later dates in order named.] Length 5.5-7 mm. Width 3.5-4.5 mm.

The measurements of the larva are given in tabular form, as follows:

TABLE I.—*Larval measurements (mm.) of Hypera punctata.*

Number of specimens averaged.	First instar.				Second instar.			
	Width of head.	Length of body.			Width of head.	Length of body.		
		Minimum.	Maximum.	Average.		Minimum.	Maximum.	Average.
24.....	0.2	1.9	3.4	2.7	0.55	1.8	5.9	3.8
20.....								
Number of specimens averaged.	Third instar.				Fourth instar.			
	Width of head.	Length of body.			Width of head.	Length of body.		
		Minimum.	Maximum.	Average.		Minimum.	Maximum.	Average.
18.....	0.8	3.8	9.5	6.3	1.2	5.1	13.1	9.3
19.....								

FOOD PLANTS AND INJURY.

The food plants in Europe are listed as *Trifolium* (clover) and *Medicago sativa* (lucerne, alfalfa). In this country all kinds of clovers, including *Trifolium pratense*, *T. incarnatum*, *T. hybridum*, and *T. repens* are eaten, as well as alfalfa and sweet clover (*Mililotus alba*). Webster reported white clover being eaten in preference to red in Ohio, but other observers, including the present writers, have noted that red clover and alfalfa are more often chosen. Both larvæ and adults will feed on beans, and the adults have been observed eating timothy, burdock, soy bean, and the flowers of goldenrod. W. H. Larrimer observed beetles feeding on corn foliage at McFarland, Kans., August 10, 1915.

In Europe this species has several times been reported as injurious locally, but only for short periods. The earliest record I have found is Villa's statement at the time of the outbreak in the region of Lombardy in 1868 when he says that Moretti in a revised edition of Gene's publication in 1853 reports this species as injuring clover and believes that this referred to a previous serious injury about 1834-35. * * * In 1868 the species caused serious damage in Northern Italy so that a commission was appointed to investigate the matter and published several papers giving recommendations. Targione-Tozzetti in 1879 notes a severe outbreak in the region around Florence. It was again injurious in the region of Florence in 1902-3. (Titus 7, p. 408.)

The first record of the destructive work of this species in America occurred at Barrington, Yates County, N. Y., in 1881 and 1882, but since that time it has been controlled largely by an epidemic fungous disease. The clover-leaf weevil has spread rapidly over the country, and outbreaks have occurred repeatedly, but usually have been checked before serious damage was done. The most notable of these late outbreaks occurred in Michigan and persisted for a year or two before the fungus succeeded in checking the insect. In this connection Pettit (5, p. 46) records that cattle pastured on clover at the time the larvæ were being destroyed by this fungous disease were made seriously ill, and so many complaints were received in Michigan that it was advised that cattle be kept out of clover pastures until the bodies of the dead larvæ had dropped to the ground.

LIFE HISTORY.

LIFE CYCLE.

The life history of this species was first studied in the United States by Riley (6, p. 171-179) in 1882, and Folsom's paper on clover insects in 1909 (3, p. 155-164) gives much additional information. Numerous other writers have added notes on the distribution, habits, and life history, and these have been drawn on by the authors. The life cycle is one year according to observations made by the present writers, which agrees with the results obtained by Folsom. Briefly, the life cycle is as follows:

The eggs are laid in or on different parts of the clover or alfalfa plant, more often in a puncture on the stem or leaf sheath or on the outside of these parts in the fall of the year between September 8 and November 29. The eggs laid previous to October 25 hatch the same fall, and hibernate as first, second, and third instar larvæ while those laid after October 25 usually remain over winter as eggs, and, except in the case of eggs laid quite late, hatch the following March. The larvæ feed on the foliage of their hosts and become full grown by the last of May, when they spin cocoons at or just below the surface of the soil, pupating therein and issuing as adult beetles in June or July. The beetles feed on foliage of clover intermittently until September when they mate, and soon thereafter egg laying begins.

Since the period of oviposition extends over a number of weeks and, furthermore, eggs laid late in the season do not hatch until spring,

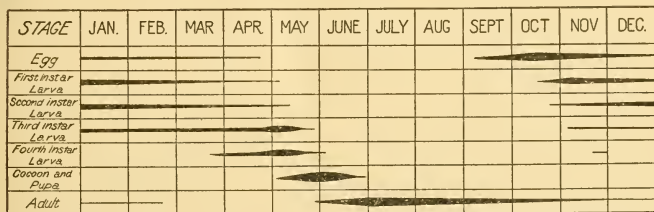


FIG. 7.—Diagram illustrating life history of the clover-leaf weevil and indicating the abundance of the different stages during the season in the latitude of La Fayette, Ind.

the various stages greatly overlap. The accompanying diagram (fig. 7) illustrates graphically the life cycle of *Hypera punctata*.

The experiments made by the authors were not started until September 8, 1915, but some of the beetles collected September 1 had oviposited previous to September 8.

The eggs are laid in the fall during September, October, and the first two weeks in November, although oviposition was observed as late as November 29 in 1915. Females laid during periods of 64 to 68 days and individuals laid the following numbers of eggs: 74, 83, 108, 162, 166, 176, 181, 196, 287. Following the last oviposition the females lived from 1 to 16 days, and all the males and females used in the experiments in the fall of 1915 and kept out of doors under normal conditions were dead by February 18, 1916.

The beetles laid consistently between September 8 and November 15, there being a marked increase in the numbers laid between October 15 and November 15. After November 15 the laying records were scattered. It was noticeable that none of the eggs laid after October 21 hatched previous to March 1, 1916, except in one case when eggs laid October 25 hatched during a period of

mild weather between December 20, 1915, and February 18, 1916. Since eggs laid after November 13, in 1915, failed to hatch the following spring, it appears that partial development of the embryo previous to cold weather is necessary to enable the egg to survive the winter. Approximately 30 per cent of the eggs overwintering in vials hatched, but it is probable that this is below the normal under natural conditions.

The eggs, which are a watery yellow when laid, soon grow darker yellow and early in the fall turn dark in from 2 to 6 days. The last laid eggs may retain their yellow color through the winter, all development being arrested. Early in the fall the eggs that have darkened become sculptured in a day or two, but later on the time elapsing between these changes may be lengthened to weeks or months. The next noticeable change in the egg is the rapid pigmentation of the head of the embryo which appears beneath the shell as a distinct round black spot. In the early fall the egg hatches in from 1 to 3 days after this change, although later such eggs may go through the winter in this condition or may hatch during some of the mild winter days.

During the fall of 1915 the shortest egg period was 13 days, the eggs being laid September 10, and the longest period, excepting for overwintering eggs, was 46 days, the eggs in this case being laid October 21. The average of the records of 50 lots of eggs between September 8 and October 21 was 25.8 days.

Just previous to hatching the embryos are active within the egg and can be seen moving around. They emerge by cutting a small round hole large enough for the larva to pass through, usually near one end of the egg. The eggshells are never eaten by the larvæ after they have emerged. The larvæ will commence feeding at once if placed on clover leaves, but may live a long time without food, as in the case of those hatching during the winter. The length of the larval stages is very variable in the fall, for feeding is suspended during adverse weather and resumed in mild. The shortest time secured for the first stage was 13 to 14 days, for the second stage 12 to 14 days, and for the third stage 10 days. No fourth-stage larvæ were obtained in these experiments during the fall as the cold weather sent the larvæ into hibernation. Table II summarizes the lengths of the different stages and larval instars as observed at La Fayette, Ind., in the spring and early summer.

Numerous larvæ were collected on different dates during the winter to determine the ages of the wintering larvæ and the results of such collections are given in tabular form in Table III. No adults were found by the authors but Folsom (3) records that hibernating adults collected in the spring were much enfeebled and unable to lay eggs. He suggests the possibility of a second generation of beetles farther south which hibernate and oviposit in the spring,

and observations made by different members of the Bureau of Entomology would indicate that ovipositing beetles in the latitude south of southern Indiana are capable of laying fertile eggs in the spring and that two broods sometimes, if not ordinarily, occur annually.

The larvæ have often been observed feeding during the mild days of winter on the small leaves at the crown of the clover plant. In the early spring the larvæ commence to feed as soon as the clover starts its growth, but feeding and growth are intermittent, due to climatic changes, so that larvæ of all stages may be found during April and May. Larvæ in the first three instars are most numerous in April, but beginning with May there is a gradual falling off in numbers of larvæ in the first two instars, those in the third and fourth predominating. By the end of May few active larvæ remain and by June 20 practically all have completed their growth and spun their pupal cocoon. Tables II and III give the number of days passed in different stages and the dates of their occurrence in the field.

TABLE II.—*Hypera punctata*: Length of larval and pupal periods.

Stage.		Number of examples.	Minimum.	Maximum.	Average.
			Days.	Days.	Days.
Larva.....	First instar.....	6	17	20	18 $\frac{3}{4}$
	Second instar.....	19	4	15	10
	Third instar.....	23	4	13	8 $\frac{1}{2}$
	Fourth instar.....	32	8	21	14 $\frac{1}{2}$
	Spinning cocoon.....	57	1	2	1+
	Prepupa.....	44	1	10	4
Pupa.....		53	5	16	11 $\frac{1}{10}$
Length of time remaining in cocoon after adult.....		56	1	5	2 $\frac{1}{2}$

TABLE III.—*Hypera punctata*: Stages occurring in field at different dates.

Date collected.	First stage.	Second stage.	Third stage.	Fourth stage.	Pre-pupa.	Pupa.
1915.						
Oct. 14.....	2					
Oct. 19.....	2	3				
Oct. 20.....	1					
Oct. 21.....	1	3				
Oct. 22.....	1	1				
Oct. 27.....	18	2				
Nov. 4.....	19	19	2	1		
Nov. 23.....	18	45	14	1		
Dec. 13.....	32	34	13			
1916.						
Jan. 3.....	6	7	1			
Jan. 28.....	33	28	5			
Mar. 25.....		3	4	1		
Mar. 31.....	1	6	4			
Apr. 3.....		6	4	1		
Apr. 5.....	2	4	2	2		
Apr. 10.....		3	2			
Apr. 15.....	10	15	12	4		
Apr. 18.....		4	1			
Apr. 20.....	3	2	1			
Apr. 27.....	2	5	9	6		
May 5.....	2	11	14	14		
May 8.....			9	9	3	
May 18.....			10	10	1	
May 25.....				2	1	1
May 26.....				4		

The cocoon (fig. 6) is spun in an oval cell made by the larva in the soil just beneath the surface or among the stems and rubbish at the base of the clover plant. This cell is formed by the larva turning around and around with its body in the characteristic curved position and is smoothed with its head. The spinning is done by the mouth but the bulk of the spinning material is drawn from the anus and every few minutes during the construction of the cocoon the larva reaches back to the anus for a fresh supply. Knab (4) shows by his dissections of these larvæ that there is an enormous development of the malpighian tubes and reasonably supposes that the bulk of the spinning material primarily arises in these tubes and is drawn from the anus by the larva. He further observes that the necessarily smaller amount of silk produced by the silk glands which open into the mouth may be used in waterproofing the other materials, for he has noticed the larva passing its mouth along the threads after they have been drawn out and put in place.

The cocoon is spun in from 1 to 2 days and the larva pupates within four days after the cocoon is completed. In one instance at La Fayette, during excessively hot weather, a larva pupated within a day after completing the cocoon, and in another instance under adverse conditions this prepupal period extended over 10 days. The newly formed pupa is pale green but later changes to yellow and finally to a brownish color.

The beetle issues 5 to 16 days after pupation, the average pupal period, according to our observations, being 11 days. The adult is at first soft and pale green, the wings protruding beyond the elytra, the pupal and larval skins remaining as a small shriveled pellet at an end of the cocoon. The elytra gradually become silver, iridescent, and pale green through which the maculations are faintly visible, the ventral surface of the abdomen is pale green, the lower part of the head reddish brown, the prothorax tan colored. The wings are soon withdrawn beneath the elytra and within 24 hours the insect has become mature, after which the beetle issues by eating an irregular hole in the cocoon. The first beetles issuing at La Fayette in 1916 emerged on May 26 and the last June 26, although other observers in the same latitude give the period of greatest emergence as the last week in June, the period of emergence extending from May 9 to July 15.

After emergence the beetles feed during the night and conceal themselves during the day under rubbish or in cracks in the ground. They feed steadily for about two weeks, after which they become semidormant and remain inactive until about the first of September, whereupon they become sexually active.

COPULATION.

As stated, the beetles resume activity the last of August or the first of September. The record of copulation for one pair reads September 15, October 4, 8, 14, 17, 27, and November 7, the female of this pair laying 196 eggs between September 25 and November 27. As these beetles were examined but once or twice each day probably only a few of the copulations were observed. Mating probably takes place normally during the day, for beetles in copula have been collected in the field only at this time.

OVIPOSITION.

The records of other writers give as places of oviposition the ground, base of plant, stems, and the inside of dead stems. Careful search was made in the field for eggs during the laying season, but only three were found, these being placed singly on dead stems. In the breeding cages the beetles rarely laid on the ground but in or on some portion of the plant. When fed alfalfa they laid the eggs singly in punctures in the stem. (Fig. 3.) Sometimes it seemed impossible for the beetle to make punctures enough to contain all the eggs she wished to lay, so she would fasten several in a mass on the stem by means of a rapidly drying secretion. When fed clover the females practically always laid inside the petiole or the leaf sheath; and if these were not present and only stems provided, the eggs were laid as in alfalfa. In laying the eggs in the petioles the female usually cut a hole with her mandibles just large enough to admit one egg at a time, through the side of the petiole, but in the case of an old matured petiole a cavity would be made into which the ovipositor could be thrust and from 1 to 23 eggs laid, part of which would be pushed up and part down the stem. Measurements showed that the eggs were sometimes pushed in the petiole as far as $3\frac{1}{2}$ mm. above and 6 mm. below the puncture. Unless the last egg was left in the opening, as infrequently occurred, the opening practically healed before the eggs hatched. In case the petiole was solid, the inside would be eaten out and the eggs laid as before. It was noticeable that petioles and their leaves never appeared to be injured when eggs were laid in them. The eggs were also readily laid in the sheath at the base of the petiole, a tiny hole being cut through its side and a mass of eggs deposited within, as many as 33 eggs being laid by one female at one time in this way. In all the experiments the largest number of eggs laid by one female at one time was 34, 18 to 25 being common. The eggs are usually laid at night but some were recorded between 8 and 9 a. m., and it was noticeable that there was a marked tendency to lay during the day in the fall when the nights were very cold.

HABITS.

The young larvæ feed during the day, largely on the underside of the leaves, eating small holes in them. Whether they feed from the underside because it is more protected or because there are more epidermal hairs for them to cling to is not known. After the third molt they eat patches from the edges of the leaves, feeding only at night, and dropping to the ground when disturbed, curling themselves tightly end to end. During the day they lie coiled at the base of the plant, hiding under dead leaves and other débris.

The larvæ are legless but are supplied with pairs of muscular fleshy tubercles on the ventrum of the segments and these are used in grasping epidermal hairs, edges of leaves, etc. The young larvæ move about by grasping the epidermal hairs with their mouths, the folds between segments, and the transverse folds. Older larvæ ascend petioles spirally, using the muscular abdomen as a means of locomotion, and with each successive advance securing a new hold with the mouth and forepart of the body. As this is repeated, the larvæ move around and around the stem with a spiral motion.

When handled, the larvæ will often emit a greenish saliva, which appears to be for defensive purposes, and in addition may pass their blackish semiliquid waste.

The young larva molts by first coiling itself about a bunch of epidermal hairs and then crawling out of the larval skin, which opens in the head region, leaving the empty skin coiled around the hairs. The larvæ have never been observed to eat the cast skins.

The adult, after casting off the pupal skin, which shrivels to a small pellet at one end of the cocoon with the last larval skin, soon eats its way out and feeds during the summer, ragging the clover leaves and sometimes eating the plants to the ground. During the day they usually hide under rubbish or in cracks in the ground but have been observed to feed, and many have been collected by sweeping the tops of clover plants at this time.

FEEDING EXPERIMENTS.

Feeding experiments were conducted at La Fayette, Ind., to determine the amounts of clover foliage eaten by *Hypera punctata* at different seasons and during the larval and adult stages (Table IV). The amount of food eaten by individual larvæ averages 3.09 square inches of red clover foliage from 25 examples studied, and of this amount 2.48 square inches, or approximately 80 per cent, is consumed during the last instar. Comparatively small amounts of leaf tissue are eaten during the first three instars—0.019 square inch being eaten during the first, 0.087 in the second, and 0.504 in the third instar (Table V and fig. 8).

As has already been noted, the beetles begin to feed immediately upon issuing in May and June and continue for a period of about two weeks. They then become dormant and do not resume feeding until early in September, coincident with the beginning of sexual activity. During the early period of feeding the foliage is the principal part of the clover plant eaten, but in late fall the beetles, and especially the females, show an increasing tendency to feed upon the stems and petioles.

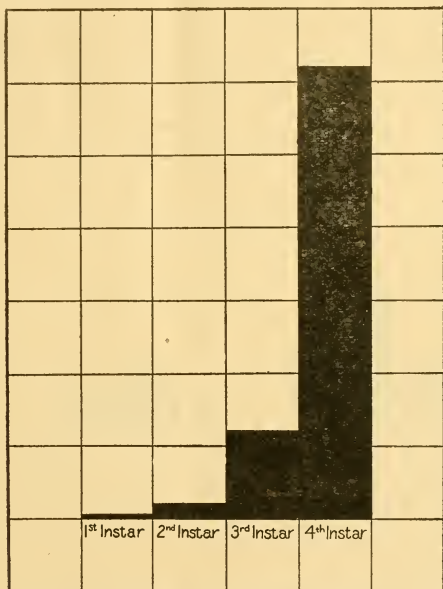


FIG. 8.—Diagram showing average comparative amounts of clover foliage consumed by larvæ of the clover-leaf weevil in their different instars.

The life of the adult, therefore, is divided into two distinct feeding periods, separated by one of inactivity during the months of July and August. During the first active feeding period enough nourishment is taken to tide the insect over midsummer when but little food is available. Beetles deprived of foliage immediately after emergence from the cocoon die within a few days. According to experiments made by the writers, the average amount of clover foliage eaten by individual beetles prior to the inactive summer period, during what might appropriately be termed the predormant period, is 3.28 square inches, which is consumed in an average of 23.5 days. Beetles issuing late in May become dormant late in June, while those emerging

from the middle to the end of June do not stop feeding until early in July. The amount of foliage eaten during the postdormant period, that is, after the summer inactive period, is 1.48 square inches and extends over an average of 82 days, that is, not one-tenth as much per day as is eaten in the predormant stage (Table VI and fig. 9).

The amount of food consumed by the individual beetle during its entire adult stage averages 4.76 square inches, 0.045 of an inch per day during the feeding periods. The feeding by the beetles is therefore so slow and gradual that they seldom do an appreciable amount of injury except when in unusual numbers. On the other hand, the larva needs approximately 2 square inches less of foliage for its development than is eaten by the adult, but of the 3.09 square inches of leaf eaten by each larva, 2.48 inches are consumed during the last instar, which occupies a period of 10 days or less, and the large amount of foliage taken in so short a period greatly increases the liability of injury.

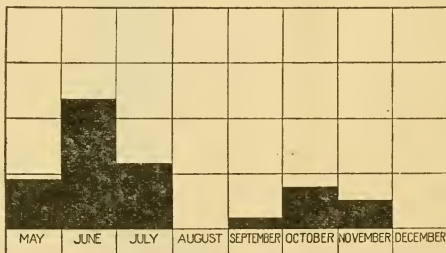


FIG. 9.—Diagram showing the comparative amounts of clover foliage eaten by adult beetles of the clover-leaf weevil during the different months of the season.¹

Tables IV, V, and VI give the amounts of clover foliage eaten by adults and larvæ.

TABLE IV.—Average amounts of clover foliage eaten by adult and larva of *Hypera punctata*.

Stage.	Average amount food eaten.	Average length feeding period.	Average per day.
	<i>Inches.</i>	<i>Days.</i>	
Predormant beetle.....	3.28	23.5	0.139
Postdormant beetle.....	1.74	82.0	.009
Larva 1st instar.....	.019	18.6	.001
Larva 2d instar.....	.084	10.0	.008
Larva 3d instar.....	.504	8.5	.059
Larva 4th instar.....	2.480	14.0	.177
Total—larva.....	3.087	51.1	.06
Total—beetle.....	4.02	105.5	.038

¹ The beetle consumes at least an equal amount of stem during this period and this could not be measured.

¹ As recorded in Table IV, at least an equal amount of stem is eaten in the fall in addition to the foliage, and due consideration is taken of this fact.

TABLE V.—Amount (inches) of clover foliage eaten by larvæ of *Hypera punctata*.

Cage No.	First instar.	Second instar.	Third instar.	Fourth instar.	Total.
Laf. D454:					
ba.....	0.0025	0.08	0.66	2.14	3.1425
bb.....	.005	.1	.2525	2.4121	2.7696
bc.....	.005	.055	.195	2.415	2.67
bd.....	.0025	.005	.62436	2.80952	3.4414
bf.....	.0025	.03	.37		
bg.....	.015	.06	1.23868	2.668	3.9817
bh.....	.01	.11	.54	2.90332	3.5633
bi.....	.0275	.08	.2975	2.61	3.015
bk.....	.005	.05	.80428	2.27668	3.29
bl.....	.03				
bml.....	.005				
bn.....		.1025	.38375	2.70375	
bo.....	.025	.1025			
bq.....	.03	.18			
br.....	.025	.12	.47748	2.85104	3.4735
bs.....	.03	.396	1.0034	1.11412	2.5435
bt.....	.02	.035			
bu.....	.04	.09	.77892	3.05864	3.96756
bv.....	.01	.055	.905	1.945	2.915
bw.....	.0125	.025			
bx.....	.04	.1	.5125	2.7475	3.395
baa.....		.025	.7825	1.8175	
bab.....	.0125	.1925	.763		
bac.....	.0275	.04	.7725		
bad.....	.025	.035	.495	2.4325	2.98
baf.....	.0325				
bag.....	.065	.1	.4428	1.94452	2.5524
bah.....		.0375	.2825	1.465	
bai.....	.025				
bj.....	.0225	.025			
bak.....	.0125				
bal.....	.03				
bam.....	.01				
ban.....	.0075				
bao.....	.01				
bap.....	.014	.035	.3475	1.6125	2.009
baq.....	.03	.04844	.56052	2.40124	3.0401
bar.....	.045	.07612	.3806	2.23516	2.7369
bas.....	.01	.0525	.07275	1.9425	2.0778
bat.....	.02	.1			
bau.....	.0175	.055	.5875	2.2475	2.9075
bav.....	.008	.04	.465	3.205	3.718
baw.....	.01	.145	.3125		
bay.....	.01	.03			
baz.....	.02	.05536	.63664	2.66892	3.3809
ca.....	.02	.08304	.346	2.87872	3.3277
cb.....	.01	.1221	.3375	1.845	2.3146
cj.....	.02	.025			
ck.....	.0025	.0675	.51	2.11	2.69
cl.....	.0325	.0375			
cm.....		.0775	.225		
cn.....		.0625	.825	2.7025	
cp.....			.4675	3.0625	
cq.....		.02	.22		
cr.....		.08	.68508	3.3908	
cs.....		.0525	.66	3.7925	
ct.....		.242			
cu.....		.0375	.3875	3.4425	
cam.....			.455		
Average.....	.019	.0874	.50401	2.48035	3.09076

TABLE VI.—Amounts (inches) of clover foliage eaten by beetles of *Hypera punctata*.
DURING PREDORMANT PERIOD.

Cage No.	Number of beetles per cage.	Date of emergence.	Date stopped feeding.	Total feeding period	Amount of foliage eaten during—				Sex.
					May.	June.	July.	Total.	
				<i>Days</i>					
D363a.....	1	May 25	June 20	26	1.36	1.08	.....	2.44	♂
D363b.....	1	May 26	June 14	19	1.19	2.46	.....	3.65	♂
D363g.....	1	May 28	June 20	23	.25	3.13	.....	3.38	♂
D363n.....	1	June 3	June 27	24	.....	4.9	.....	4.9	♂
D363s.....	1	June 4	June 30	26	.....	5.61	.....	5.61	♂
D363t.....	1	do.....	do.....	26	.....	4.39	.....	4.39	♂
D363aa.....	1	June 13	July 5	23	.....	3.07	0.93	4.00	♂
D363ad.....	1	June 15	July 8	24	.....	3.56	.84	4.4	♂
D363ag.....	1	June 17	July 7	21	.....	2.51	.52	3.03	♂
D568a.....	2	June 27	July 10	24	.....	1.06	2.19	3.25	♂
D568c.....	2	do.....	July 8	22	.....	2.39	2.6	4.99	♂
D568d.....	2	do.....	July 10	24	.....	1.46	3.73	5.19	♂
Total average per beetle.....				23.5	.93	2.37	1.2	3.28	

DURING REPRODUCTIVE PERIOD.

Cage No.	Number of beetles per cage.	Amount of foliage eaten during—				Total period.	Sex.
		September.	October.	November.	December.		
D363a.....	2	0.152	0.792	0.498	0.149	1.591	♂
D363b.....	3	.....	.754	.228	.032	1.014	♂
D363g.....	2	.104	1.240	.430	.232	2.006	♂
D363n.....	2	.080	.922	.283	.155	1.440	♂
D363s.....	2	.045	.640	.459	.346	1.490	♂
D363t.....	2	.436	.818	.440	.280	1.974	♂
D363aa.....	2	.249	.461	.503	.195	1.408	♂
D363ad.....	2	.285	1.221	.....	.....	1.506	♂
D363ag.....	2	.....	.806	.505	.138	1.449	♂
D454e.....	2	.....	.844	1.341	.690	2.875	♂
D454h.....	3	.....	.376	.563	.136	1.075	♂
Total average per beetle.....		.0965	.369	.239	.011	.7155	

NATURAL ENEMIES.

The most important check on the abundance of *Hypera punctata* is the fungous disease *Empusa sphaerosperma* Fres., which kills the larvæ in vast numbers during the months of April and May and again in October and November. This disease is epidemic, and contagion so rapid and thorough that in from two to four weeks it is almost impossible to find living individuals where previously there were thousands.

The sick larvæ of all ages crawl up the herbage during the night, and instead of again concealing themselves near the ground on the approach of light, as the healthy ones do, ascend as high as possible, and if on grass, coil themselves in a horizontal position about the apex of the blade, or if on other objects, take a position as nearly similar as the shape of the object permits. If disturbed before the middle of the forenoon the majority are still able to crawl, although sluggishly; by noon most of them are quite dead, but unchanged in appearance. . . . Late in the afternoon, the body has changed from the normal yellowish or pea green and smooth appearance to velvety gray. The next morning there is only a small, blackened and shriveled mass remaining, while the surrounding foliage is powdered with a whitish, clinging dust, composed of the spores of the fungus. (J. C. Arthur (1, p. 285-289).)

The fungus mycelia ramify through the body of the larva, absorb the body fluids, but do not penetrate the tracheal or alimentary tract. A portion of the mycelium pushes out through the ventral side of the larva and forms rhizoids attaching the larva securely to its support. Other mycelial threads push out from other portions of the body and form a gray velvety coating over the body of the larva. On the tip of some of these branches is formed a spore which is projected forcibly into the air to infect other larvæ with which it may come in contact. These are the temporary spores and germinate at once to infect new hosts. Resting spores are also formed and these develop in the body of the larva and are capable of retaining their virility for a longer time.

This disease is well distributed in the United States and attacks numerous other insects, among them the common cabbage worm (*Pontia rapae* L.), mosquitos, flies, ichneumon wasps, and certain leafhoppers.

According to Riley the larva of a small beetle (*Collops quadrimaculatus* Fab.) feeds on the eggs of the clover-leaf weevil and one of the tiger-beetles (*Cicindela repanda* Dej.) probably preys on the larvæ. In Europe several larval parasites are known but none have been recorded from this country. H. L. Parker, of the Bureau of Entomology, collected a clover-leaf weevil larva at Hagerstown, Md., April 30, 1915, bearing a tachinid egg, but the adult was not reared therefrom.

Poultry, especially turkeys and chickens, are fond of the larvæ and beetles, and if given the opportunity will consume large numbers.

Birds are valuable and important natural checks on this insect and according to the Bureau of Biological Survey (2, p. 7),

The common or large clover-leaf weevil is the prey of 25 species of birds. The nighthawk, crow, red-headed woodpecker, purple martin, and crow blackbird have the best records for the destruction of adults, and the Savannah and vesper sparrows of the larvæ.

In literature we find the following birds listed as feeding on *Hypera punctata*:

American crow.....	<i>Corvus brachyrhynchos.</i>
Bobolink.....	<i>Dolichonyx oryzivorus.</i>
Bobwhite.....	<i>Colinus virginianus.</i>
Catbird.....	<i>Dumetella carolinensis.</i>
Crow blackbird.....	<i>Quiscalus quiscula.</i>
Flicker.....	<i>Colaptes auratus.</i>
Horned lark.....	<i>Otocoris alpestris flava.</i>
Kingbird.....	<i>Tyrannus tyrannus.</i>
Meadowlark.....	<i>Sturnella magna.</i>
Nighthawk.....	<i>Chordeiles virginianus.</i>
Purple martin.....	<i>Progne subis.</i>
Red-headed woodpecker.....	<i>Melanerpes erythrocephalus.</i>
Robin.....	<i>Planesticus migratorius.</i>
Sparrows:	
English.....	<i>Passer domesticus.</i>
Savannah.....	<i>Passerculus sandwichensis savanna.</i>
Vesper.....	<i>Poæcetes gramineus.</i>
Wood pewee.....	<i>Contopus virens.</i>

Toads and frogs sometimes prey upon the weevils. Mr. T. S. Wilson, of the Bureau of Entomology, found one adult in a toad's stomach at Wellington, Kans., July 12, 1915, and Mr. H. L. Parker found 11 adults and one pupa of *Hypera punctata* in the stomachs of four frogs (*Rana* sp.) collected at Bridgeport, N. Y., December 6, 1915, out of 14 examined.

CONTROL.

The outbreaks of this insect are eventually suppressed by the fungous disease mentioned and, except in rare cases, before serious damage is done. Often what promises to be a serious attack is wiped out by the disease just as it seems to appear most threatening, or, as was the case in 1917, the weather conditions may enable the clover to make a rank growth and overcome injury by the larvæ, even though they may be present in enormous numbers.

Usually the need of remedial precautions does not become apparent until too late to apply practical measures. The insect does not ordinarily become abundant in a clover field until the second season, and in localities where it is known to occur in occasional or frequent abundance it is a good practice to pasture lightly all first-year clover in the fall or to clip it back in spring and further to hinder the increase of this insect in the locality by thoroughly plowing under the second year crop in the fall.

Other measures, such as burning clover fields in winter, rolling, dragging, and flooding, have been advised, but the practical value of these measures has not been proved; and clipping and plowing under clover at the end of the second season, in themselves valuable in the control of other clover insects as well as being good farm practices, seem all that is necessary, as a rule, for prevention of injury.

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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

April 19, 1921

STUDIES IN THE BIOLOGY OF THE MEXICAN COTTON
BOLL WEEVIL ON SHORT-STAPLE UPLAND, LONG-
STAPLE UPLAND, AND SEA-ISLAND COTTONS.^a

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Investigations.*

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INTRODUCTION.

The studies in the biology of the Mexican cotton boll weevil (*Anthonomus grandis* Boh.) upon which this paper is based were con-

^a The cotton varieties used in these studies were a short-staple upland cotton known as King, a long-staple variety known as Webber No. 49, and a sea-island cotton known as Hope Straight.

ducted at Madison, Fla., during the years 1918 and 1919. The results recorded herein in addition to representing the first serious study of the boll weevil east of the Mississippi River also indicate the rapidity with which the weevil is adapting itself to new environmental conditions in its spread eastward.

Owing to the very decided effect of climatic factors on the biology of the boll weevil, it has been found necessary to study the development of the weevil under both field and outdoor insectary conditions.

In order to throw some light on the possibility of growing sea-island cotton under weevil conditions, a comparative study of the biology of the weevil on upland, long staple, and sea-island cottons is included herewith. Since all methods of control are usually based upon facts secured from biological studies, the results of the life-history studies recorded herewith are of considerable importance to the cotton growers east of the Mississippi River.

HISTORICAL REVIEW.

A review of the studies in the life history of the boll weevil is presented herewith.¹ This review is of interest in that it shows the times and conditions under which studies have been conducted.

The earliest work was that at Victoria, Tex., in 1902 and 1903, the results being published early in 1904.² This was followed by similar investigations at the same place during 1904, and the results of these studies were included in a bulletin issued in 1905.³

During 1910 similar investigations were conducted at Tallulah, La., and the results were published in 1911.⁴

Then, in 1912, these studies and such others as had been made elsewhere were brought together in a large bulletin.⁵

During 1913 another series of studies was conducted at Victoria, Tex., to check those which had been made at the same place 10 years earlier. It was found that the weevil had made a number of important changes in its life history, principal among these being a much greater adaptability to plants other than cotton as food. The biology of the Arizona *Thurberia* weevil was also studied, and this variety was hybridized with the Texas cotton weevils. The results of these studies are included in three papers.⁶

¹ Quoted from Howe, R. W., Bul. 358, U. S. Dept. Agr., p. 2-3.

² Hunter, W. D., and Hinds, W. E. The Mexican Cotton Boll Weevil. U. S. Dept. Agr. Bur. Ent. Bul. 45, 116 p., 16 pl., 6 figs., 1904.

³ Hunter, W. D., and Hinds, W. E. The Mexican Cotton Boll Weevil. U. S. Dept. of Agr. Bur. Ent. Bul. 51, 181 p., 23 pl., 8 figs., 1905.

⁴ Cushman, R. A. Studies in the biology of the boll weevil in the Mississippi Delta region of Louisiana. *In* Jour. Econ. Ent., v. 4, no. 5, 1911. p. 432-448.

⁵ Hunter, W. D., and Pierce, W. D. Mexican Cotton Boll Weevil. U. S. Dept. of Agr. Bur. Ent. Bul. 114, 188 p., 22 pl., 34 figs., 1912.

⁶ Coad, B. R., and Pierce, W. D. Studies of the Arizona *Thurberia* weevil on cotton in Texas. Proc. Wash. Ent. Soc., v. 16, no. 1. p. 23-28. 1914.

Coad, B. R. Feeding habits of the boll weevil on plants other than cotton. U. S. Dept. Agr. Jour. Agr. Res., v. 2, no. 3, p. 235-245. 1914.

Coad, B. R. Recent studies of the Mexican Cotton Boll Weevil. U. S. Dept. Agr. Bul. 231, 34 p., 1 fig. 1915.

In 1914 the life history and habits of the Arizona weevil were studied under natural conditions in the mountains near Tucson, Ariz. These studies are discussed in two papers.⁷

Thus it is seen that these studies embrace a wide range of time and conditions. In fact, the conditions of humidity, rainfall, temperature, altitude, soil, etc., include practically all extremes found in the cotton belt.

SCOPE OF THE PRESENT LIFE-HISTORY STUDIES.

The biological studies of the boll weevil at Madison, Fla., during the year 1918, included a thorough study of the boll weevil under outdoor insectary conditions on both upland and sea-island cottons. The main object of this study was to determine the difference, if any, in the weevil's biology on the two kinds of cotton. During the month of August, 1918, a small series of experiments was made to determine the length of the developmental period of the weevil from egg to adult under actual field conditions. The results of the field studies indicated conclusively that a wide variation existed in the length of time required for the developmental period of the weevil under insectary conditions compared with the true developmental period under normal field conditions. Consequently the studies in the biology of the weevil during the year 1919 were arranged to include a thorough study of the field biology of the boll weevil. Insectary studies in the biology of the weevil were conducted at the same time the field tests were under observation, to serve as a check.

METHODS USED IN THE STUDY OF THE BOLL WEEVIL UNDER OUTDOOR INSECTARY CONDITIONS.

The numerous experiments of 1918 were conducted in a specially constructed outdoor insectary at the Madison, Fla., laboratory (fig. 8). The sides of the insectary building were constructed entirely of 16-mesh galvanized wire screen from the floor to the ceiling, which permitted free air circulation at all times. The roof of the insectary building extended 2 feet over the sides of the building, preventing the direct rays of the sun from touching any of the breeding jars. All the insectary breeding work was conducted in glass tumblers half filled with white sand. The sand was kept constantly moist. Lantern globes with cheesecloth covers were used for the longevity experiments.

⁷ Coad, B. R. Relation of the Arizona Wild Cotton Weevil to Cotton Planting in the Arid West. U. S. Dept. Agr. Bul. 233, 12 p., 4 pl. 1915.

Coad, B. R. Studies on the Biology of the Arizona Wild Cotton Weevil. U. S. Dept. Agr. Bul. 344, 23 p., 2 pl., 1 fig. 1916.

Large 16-mesh galvanized-wire screen cages 3 by 3 by 4 feet high were used in conducting the field biological studies of the weevil. The cotton plants used in the breeding work were first examined carefully to make certain that no infested squares were present. The large cages were then placed over the plants and a male and a

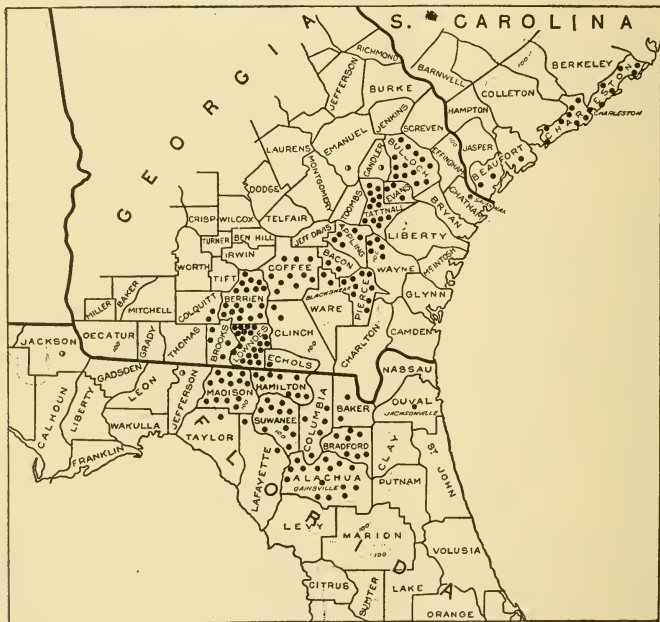


FIG. 1.—Map of the sea-island cotton area of the United States showing distribution by counties. Each dot represents an average production of 500 bales. (From Orton, Bur. Plant Industry, U. S. D. A.)

female boll weevil liberated in each cage. On the following day all squares found with egg punctures were recorded, each infested square bearing a light string tag showing the number of the weevil and the date of the egg puncture. After the squares were examined and tagged the cage and weevil were removed to a noninfested plant and the process repeated. Daily observations were made on the plants bearing the tagged squares and the date the infested square dropped off the plant was recorded on the tag. As soon as the infested squares dropped off the plants they were placed in a field hatchery

(fig. 7). The field hatchery consisted merely of a certain area in the cotton field about 20 feet square. The infested squares were placed in the hatchery beneath the cotton plants in the natural position of fallen squares. After 15 days from the date of egg puncture the infested squares were placed in small wire-screen hatching cages (fig. 7). The hatching cages were constructed of 16-mesh wire without bottoms and protected the infested squares in such a manner that the squares received about the same amount of sunshine and moisture as under normal field conditions. Maximum and minimum thermometers were installed in the field hatchery (fig. 9). Both instruments were resting on the soil in order that the exact minimum and maximum temperatures to which the developing weevil was subjected under field conditions might be determined.

Ten hibernated male and female weevils were used to secure the developmental period of the first generation of weevils on upland cotton. In addition, 10 hibernated female weevils that had not been fertilized were used to determine the effect of nonfertilization after emergence from hibernation on the progeny produced. When the first generation weevils became adults 10 pairs were selected and used for securing the fecundity records on upland, long staple, and sea-island cottons. The fecundity records for the second generation on upland cotton were secured in a like manner. After the 15th of August, however, the weevils had developed so rapidly in the field that it was necessary to discontinue the study of the developmental period of the weevil for each successive generation.

For securing the effect of the lower fall temperatures on the developmental period of the weevil, upland cotton plants were stripped of all cotton squares and then caged. As soon as the plants grew new squares female weevils were placed in the cages for oviposition purposes. About every 20 days a new series of developmental studies was inaugurated. This process was continued until frost killed the cotton plants in late fall.

FOOD PLANTS OF THE BOLL WEEVIL.

Owing to the economic importance of the question as to whether or not the boll weevil can adapt itself to plants other than cotton for food, this phase of the life history has been carefully studied in practically every section of the cotton belt.

The boll weevil has as regular food plants the cultivated cottons of the United States, Mexico, Cuba, and Central America, and certain wild cottons, including *Gossypium davidsoni* on the coast of the Gulf of California, and also the so-called wild cotton, *Thurberia thespesioides*, in Mexico and Arizona.

The breeding experiments of Coad and Howe, both published, show that the weevil can live on Hibiscus, and Coad reared an adult from Hibiscus, but the weevil can not normally attack the plant. So far as we know, there are no plants growing in Florida or the southern States that are adapted to serve as food plants of the boll weevil.

THE BOLL WEEVIL ON SEA-ISLAND COTTON.

FEEDING EXPERIMENTS TO DETERMINE THE PREFERENCE SHOWN BY THE BOLL WEEVIL FOR SEA-ISLAND COTTON.

A known number of adult boll weevils were placed in battery jars and allowed to feed on bolls, squares, and leaves. Each jar contained both sea-island and upland bolls, squares, and leaves, and careful records were taken every two hours to determine whether there was any preference by the weevil for either of the two types of cotton fruit and foliage. The experiments were conducted in an outdoor insectary where normal atmospheric conditions prevailed. The data obtained in order to ascertain whether there is any preference by the boll weevil for sea-island as compared with upland cotton are given in Table I. The records presented in this table show that the boll weevil seems to prefer sea-island foliage to upland foliage, and that it shows a distinct preference for sea-island bolls compared with upland bolls. It appears also that there is a tendency to feed on upland squares in preference to sea-island squares.

TABLE I.—*Feeding choice of boll weevil between sea-island and upland cotton, Madison, Fla.*

Food.	Number weevils used in experiment.	Total number individual observations.	Total number of times weevils were observed.			Percentage of feedings recorded on—	
			Feeding on upland cotton.	Feeding on sea-island cotton.	Resting on cage.	Upland cotton.	Sea-island cotton.
Bolls.....	10	290	64	118	108	22.0	40.6
Squares.....	10	290	135	110	44	46.9	37.9
Leaves.....	10	290	77	129	84	26.5	44.4
Total.....	30	870	276	357	236	¹ 31.8	¹ 40.9

¹ Average.

In Table I attention is called to the preference by the boll weevil for sea-island bolls over upland bolls in the experiments conducted on the feeding habits of the weevil. In 1917, in order to secure further data on this phase of the weevil's attack, the writer examined at random each week 100 grown bolls of each variety of upland and sea-island cottons that were still green, beginning on the 19th of July, the

bolls being collected under similar field conditions. These records were continued throughout August and to the 1st of September. Table II shows the results of this examination:

TABLE II.—Record of weevil infestation in green bolls of sea-island and upland cottons, Madison, Fla.

Date of examination.	Total num- ber bolls exam- ined.	Upland cotton bolls.		Sea-island cotton bolls.	
		Num- ber clean.	Num- ber pun- ctured.	Num- ber clean.	Num- ber pun- ctured.
1917.					
July 19.....	200	91	9	74	26
July 26.....	200	89	11	81	19
Aug. 4.....	200	92	8	69	31
Aug. 11.....	200	92	8	69	31
Aug. 20.....	200	91	9	61	39
Aug. 25.....	¹ 600	36	64	² 166	³ 334
Sept. 1.....	200	38	62	29	71
Total.....	1,800	529	171	549	551
Per cent punctured.....			24.4		50.09
1 500 sea-island. 2 33 per hundred. 3 67 per hundred.					

¹ 500 sea-island.

² 33 per hundred.

³ 67 per hundred.

A careful study of Table II shows that the number of weevils attacking sea-island bolls was far greater than the number attacking upland bolls. Observations in the field also show that a great many more weevils are to be found feeding on the sea-island bolls than on upland cotton bolls.

LONGEVITY OF ADULT BOLL WEEVILS ON UPLAND AND SEA-ISLAND COTTON.

The length of time adult weevils live on upland cotton has been determined for several different times and places. The object of the longevity tests at Madison, Fla., was to determine whether there was any considerable difference in the length of life of weevils fed on upland and sea-island cottons.

Table III gives the observations on the longevity of the weevil when fed upon different parts of the upland cotton plant. The maximum longevity of 84 days was shown by a male weevil that had hibernated over the preceding winter and emerged from hibernation during the month of April. The average longevity for hibernated weevils without food was 12.7 days, compared with an average of 18.8 days for hibernated weevils fed on cotton plantlets. Adult weevils of the first and second generations lived an average of 24.3 days on cotton squares and 12.3 days on green cotton bolls.

Table IV gives the data concerning the longevity of boll weevils on sea-island cotton. The maximum longevity on sea-island cotton

TABLE III.—*Longevity record of boll weevils, summary of the observations at Madison, Fla., 1918.*

Date.	Kind of food.	Males.				Females.				Both sexes.		
		Num- ber.	Weevil days.	Aver- age lon- gevity.	Maxi- mum lon- gevity.	Num- ber.	Weevil days.	Aver- age lon- gevity.	Maxi- mum lon- gevity.	Aver- age lon- gevity.	Maxi- mum lon- gevity.	Source of weevils.
Feb. 22 to 28.....	No food.....	56	589	13.3	33	33	402	12.1	34	Days.....	12.7	Hibernated.
Mar. 1 to 31.....	do.....	48	712	14.8	40	49	900	18.3	53	Days.....	16.5	Do.
Apr. 1 to 30.....	do.....	26	363	14.03	27	27	352	13.03	34	Days.....	13.5	Do.
May 1 to 31.....	do.....	23	198	8.6	15	12	100	8.3	14	Days.....	8.4	Do.
June 1 to 30.....	do.....	1	27	2.7	27	.....	.....	.....	.....	.....	.....	Do.
Total.....		154	1,891	.....	.....	121	1,754	.....	.....	.....	.....	Do.
Average.....		.....	.....	10.68	40	.....	.....	12.93	53	.....	.....	.....
Maximum.....		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mar. 1 to 21.....	Upland plantlets.....	25	596	23.8	81	35	711	20.3	76	Days.....	22.0	Do.
Apr. 1 to 30.....	do.....	17	376	22.1	84	21	412	19.6	34	Days.....	20.8	Do.
May 1 to 31.....	do.....	24	358	14.8	39	5	61	12.5	27	Days.....	13.6	Do.
Total.....		66	1,330	.....	.....	61	1,184	.....	.....	.....	.....	Do.
Average.....		.....	.....	20.2	84	.....	.....	17.4	76	.....	.....	.....
Maximum.....		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
June 26 to 30.....	Upland squares.....	127	2,680	21.1	74	52	1,139	21.9	70	Days.....	21.5	First generation.
July 20 to 21.....	do.....	20	412	20.6	38	17	407	23.9	50	Days.....	21.5	Second generation.
Total.....		147	3,092	.....	.....	69	1,546	.....	.....	.....	.....	.....
Average.....		.....	.....	20.8	74	.....	.....	22.9	70	.....	24.3	.....
Maximum.....		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
July 6 to 8.....	Upland bolls.....	34	543	15.9	49	36	472	13.1	47	Days.....	14.5	First generation.
July 24 to 31.....	do.....	19	161	8.4	19	2	24	12	12	Days.....	10.2	Second generation.
Total.....		53	704	.....	.....	38	496	.....	.....	.....	.....	.....
Average.....		.....	.....	12.1	49	.....	.....	12.5	47	.....	12.3	.....
Maximum.....		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total upland cotton.....		420	7,017	15.94	.....	289	4,980	16.43	76	.....	84	.....

TABLE IV.—*Longevity of the boll weevil on sea-island cotton, Madison, Fla., 1918.*

Date.	Kind of food.	Males.			Females.			Both sexes.		
		Num- ber.	Weevil days.	Aver- age long- evity.	Maxi- mum long- evity.	Num- ber.	Weevil days.	Aver- age long- evity.	Maxi- mum long- evity.	Aver- age long- evity.
Apr. 1 to 30.....	Sea-island plantlets.....	3	27	Days. 9	Days. 11	3	37	Days. 12.3	Days. 13	Days. 10.6
May 1 to 31.....	do.....	22	268	12.2	35	7	76	10.9	23	11.5
Total.....		25	295	10.6	35	10	113	11.6	23	11.05
Average.....										
Maximum.....										
June to July.....	Sea-island squares.....	91	1,730	19.01	65	81	1,690	20.4	67	19.7
July 6 to 25.....	do.....	23	196	8.4	18	6	44	7.3	13	1.8
Total.....		114	1,926	13.7	65	87	1,734	13.8	67	10.7
Average.....										
Maximum.....										
July 6 to 9.....	Sea-island bolls.....	32	539	16.5	52	62	1,203	19.4	43	52
July 24 to 28.....	do.....	20	201	10.05	17	8	124	13.5	33	17.9
Total.....		52	740	13.2		70	1,327	17.4		12.7
Average.....										
Maximum.....										
Total sea-island cotton		191	2,961	12.5	65	167	3,174	14.2	67	12.3
Average.....										
Maximum.....										

was made by a first-generation female weevil that became adult during the latter part of June. This weevil lived a total of 67 days. The maximum length of life for the male weevils was also recorded for a first-generation weevil that became adult during the latter part of June. This weevil lived a total of 65 days. The average longevity for hibernated weevils fed with sea-island cotton plantlets was 11.05 days. The weevils lived 10.7 days on sea-island squares and 15.3 days on green sea-island cotton bolls. By comparing the average longevity of the weevil on sea-island cotton with the average longevity on upland cotton, it is clearly demonstrated that there is little, if any, difference in the food value of sea-island and upland cotton on the longevity of adult weevils.

THE SIZE OF THE COTTON SQUARE ATTACKED BY BOLL WEEVILS.

Male and female weevils feed largely on the cotton squares, except in the case of sea-island cotton, where there is a decided tendency to feed upon the bolls as well as the squares. Upland cotton squares grow very rapidly and there is little opportunity afforded for direct feeding on the very small squares, except during the period when the first squares come on the plants and again when all squares are punctured. However, sea-island squares do not grow very rapidly and a large number of the



FIG. 2.—Three sizes of sea-island cotton squares chosen for oviposition by the boll weevil.

small squares are shed by the plant from feeding and egg punctures. It has been observed that a large number of undersized weevils are produced in sea-island cotton fields. These weevils are largely the result of eggs having been deposited in undersized squares, which resulted in an undersized weevil, owing to the lack of proper larval food (fig. 2). When a large number of sea-island squares are offered a female it has been observed that she invariably chooses the smaller squares for oviposition purposes. No records are available to show the length of the developmental period for weevils developing in undersized squares on sea-island cotton; however, it is not thought that there is much variation from that in large-sized squares. Observations on the size of weevils bred from bolls show that, except in the case of very young bolls which shrivel and dry very rapidly, nearly all weevils produced are of normal size. Sea-island cotton bolls seldom produce small-sized weevils, as the boll is very moist and furnishes much better conditions for weevil development than upland cotton bolls.

LOCATIONS SELECTED FOR OVIPOSITION ON SEA-ISLAND AND UPLAND COTTON SQUARES.

Upland cotton squares are usually punctured at the base of the square, as is shown in Plate I, figure 2. During the writer's studies at Thomasville, Ga., in 1916, the majority of the punctures were observed, in the case of sea-island cotton, to be on the upper portion of the square. There is little proliferation around the weevil punctures on the sea-island squares, the punctures being mere specks as compared to those on upland cotton. This characteristic location for egg deposition is shown in Plate I, figure 1.

PERIOD FROM EMERGENCE TO OVIPOSITION.

Female weevils bred in the outdoor insectary required an average period of 8.9 days from the time they became adult to the date of oviposition. The period of time from emergence to oviposition varied from 6 to 20 days for weevils bred under insectary conditions.

Boll weevils bred under normal field conditions appeared to have more vitality than weevils bred under insectary conditions. A record of 38 first-generation weevils bred under normal field conditions gave an average period of 7.07 days from the time they became adult to the date of oviposition.

OVIPOSITION PERIOD OF THE BOLL WEEVIL UNDER INSECTARY CONDITIONS.

The oviposition records for the weevil on upland cotton are presented in Table V. Hibernated female weevils kept with male weevils throughout life deposited eggs over an average period of 35.9 days compared with an average period of 21.7 days for females that were not kept with male weevils. The hibernated fertilized and nonfertilized weevils deposited a total of 3,605 eggs or an average of 7.2 eggs per day per female. During the lifetime of both series of hibernated weevils an average of 171 eggs was deposited by each female. The greatest number of eggs deposited during any one day by a single hibernated female weevil, under insectary conditions, was 20. The heaviest oviposition during the lifetime of both series of weevils was from the fifth to twenty-fifth days (fig. 4). The first-generation weevils deposited eggs for a period of 39.7 days and the second generation over a period of 35.2 days. The average period of oviposition on upland cotton for all weevils under observation was 33.1 days. The relationship between the mean daily temperature and the mean daily oviposition of the hibernated weevils is shown to cor-

respond very closely; that is, the higher the mean daily temperature the higher the average number of eggs until the period of oviposition begins to decline (fig. 3).

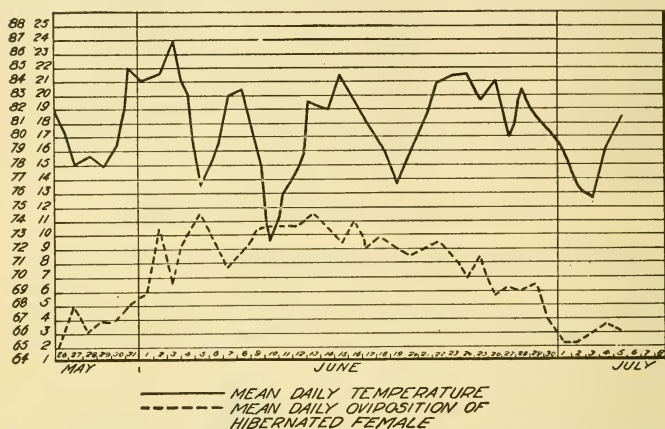


FIG. 3.—Relation of mean daily temperature to mean daily oviposition of hibernated weevils.

The oviposition records of the boll weevil on sea-island cotton differ very little from those on upland cotton under insectary conditions. The female weevils fertilized in the spring deposited eggs for an average period of 31 days and the hibernated weevils

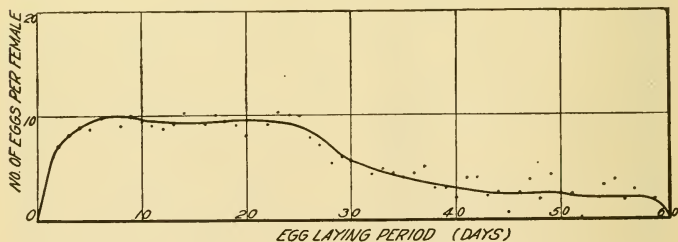


FIG. 4.—Mean daily oviposition of female weevils in upland cotton squares.

fertilized in the fall, for an average period of 27.1 days. The first and second generation weevils deposited eggs for average periods of 35.4 and 33.6 days, respectively. The average oviposition period for the females in sea-island cotton squares is shown to be 31.6 days.

TABLE V.—*Oviposition period of the boll weevil on upland and sea-island cotton squares, insectary records, Madison, Fla., 1918.*

Source of weevils.	Season.	Number of females.	Upland cotton—period.			Number of females.	Sea-island cotton.		
			Maximum.	Minimum.	Average.		Maximum.	Minimum.	Average.
Hibernated.....	May-July.....	12	<i>Days.</i> 59	<i>Days.</i> 16	35.9	15	<i>Days.</i> 52	<i>Days.</i> 18	<i>Days.</i> 31
Hibernated, fall fertilization.....	do.....	10	53	5	21.7	10	44	16	27.1
First generation.....	June-August.....	8	55	31	39.7	10	47	25	35.4
Second generation.....	July-September.	10	45	20	35.2	10	46	19	33.6
Total.....	.....	40	.....	.....	33.1	45	.....	.....	31.6

SUMMARY OF THE FECUNDITY OF THE BOLL WEEVIL ON SEA-ISLAND AND UPLAND COTTONS UNDER INSECTARY CONDITIONS.

Table VI gives a summary of the fecundity records of the boll weevil on sea-island and upland cottons. Here it is shown that the average number of eggs per day was highest with hibernated weevils for both types of cotton. The maximum number of eggs per day was made by a first-generation female on upland cotton and the maximum number per day on sea-island cotton was made by a hibernated weevil. The average number of eggs per female on upland cotton was 166.1 and the average number of eggs per day 4.92. On sea-island cotton the average number of eggs per female fell to 113.5 and the average per day to 3.8. These averages compare closely with those secured on upland cotton at Victoria, Tex., in 1913, where the females deposited an average of 212 eggs each and oviposition was at a rate of 5.9 eggs per day.

TABLE VI.—*Summary of the fecundity of boll weevils on sea-island and upland cottons under insectary conditions, 1918.*

Source.	Number of females.	Average number of eggs per female.	Average oviposition period.	Eggs per day.	
				Average.	Maximum.
Upland cotton:			<i>Days.</i>		
Hibernated.....	12	270.3	35.9	7.18	20
Hibernated, fall fertilization.....	10	117.7	21.7	5.4	19
First generation.....	8	222.8	39.7	5.6	25
Second generation.....	10	53.9	35.2	1.5	7
Total.....	40				
Average.....		166.1	33.1	4.92	
Sea-island cotton:					
Hibernated.....	15	214.7	31	7.38	19
Hibernated, fall fertilization.....	10	122	27.1	4.5	16
First generation.....	10	79.9	35.4	2.2	11
Second generation.....	10	37.5	33.6	1.11	7
Total.....	45				
Average.....		113.5	31.7	3.8	

THE AVERAGE DEVELOPMENTAL PERIOD OF THE COTTON BOLL WEEVIL UNDER OUTDOOR INSECTARY CONDITIONS.

The data on the average developmental period of the boll weevil under outdoor insectary conditions for sea-island and upland cottons are presented in Table VII. These observations extended over a period of time beginning on May 26 and ending on September 10. The maximum developmental period of any weevil from egg to adult was 18 days and the minimum period 11 days. On upland cotton 506 male weevils bred in the insectary required a total of 7,568 weevil days, or an average period from egg to adult of 14.62 days. A total of 347 female weevils bred under insectary conditions required an average developmental period of 14.8 days. The average period of development for the immature stages bred in upland cotton squares is shown to be 14.91 days.

On sea-island cotton 150 male weevils required 2,214 weevil days from egg to adult, or an average developmental period of 14.82 days. A total of 101 female weevils, bred in sea-island cotton squares, required 1,550 weevil days, with an average period of 15.06 days for development from egg to adult. There is practically no difference in the time required for development of the immature stages of the boll weevil in sea-island and upland cotton squares.

TABLE VII.—*Total developmental period of the boll weevil under insectary conditions, Madison, Fla., 1918.*

Source of weevils.	Larval food.	Oviposition period.	Males.			Females.			Both sexes.		
			Number bred.	Weevil days.	Average period.	Number bred.	Weevil days.	Average period.	Total number bred.	Total weevil days.	Average developmental period.
Upland cotton:											
Hibernated...	Cotton square.	May 26-July 27	201	2,931	14.09	126	1,812	14.38	327	4,726	14.4
Do.....	do.....	May 29-July 23	57	816	13.4	41	564	13.7	98	1,380	14.08
First generation.	do.....	June 14-Aug.15	208	3,183	15.3	133	2,029	15.2	341	5,218	15.38
Second generation.	do.....	July 17-Sept 5.	40	638	15.7	47	742	15.9	87	1,380	15.8
Total.....			506	7,568	14.62	347	5,147	14.8	853	12,704	14.91
Average.....					14.62			14.8			14.91
Sea-island cotton:											
Hibernated...	Cotton square.	May 26-July 20	67	965	13.5	46	689	13.46	115	1,654	14.3
Do.....	do.....	May 25-July 18	34	490	14.4	15	220	14.6	49	690	14.08
First generation.	do.....	June 21-Aug.15	33	498	15.09	15	249	16.6	48	746	15.5
Second generation.	do.....	July 11-Sept. 4	16	261	16.3	25	392	15.6	41	653	15.9
Total.....			150	2,214	14.82	101	1,550	15.06	253	3,743	14.94
Average.....					14.82			15.06			14.94

THE DEVELOPMENTAL PERIOD OF THE BOLL WEEVIL UNDER FIELD CONDITIONS.

Although it has been known that the factors of temperature and humidity influence the development of the boll weevil, and that laboratory breeding methods are more or less artificial, the exact difference between the life history of the weevil under field conditions and in the laboratory has never been determined.

In the experimental work at Madison, Fla., in 1918, it was found that the boll weevil in the field was requiring a considerably longer period for development than had been expected. Records tabulated by Hunter and Pierce^s showed that the length of the developmental



FIG. 5.—Cages used in the oviposition studies of the boll weevil under field conditions, Madison, Fla.

period varied with the length of time the infested squares hung on the plant after egg puncture. The Madison studies fully corroborate this statement.

The field-breeding records were secured under conditions which most nearly simulate nature. A large cage was placed over a cotton plant on which there were no infested squares (fig. 5). A single female or a male and female were liberated in the cage with the non-infested squares. On the second day if any squares were infested these were tagged (fig. 6) and the cage and weevil were then removed to a fresh cotton plant from which all infested squares had been removed. Thus day by day the weevil's maximum oviposition capacity was obtained and the infested squares remained on the plant

^s Hunter, W. D., and Pierce, W. D. *The Mexican Cotton Boll Weevil: A Summary of the Results of the Investigation of this Insect up to December 31, 1911.* Senate Document 305 (U. S. Dept. Agr., Bur. Ent. Bul. 114). 188 p., 22 pl., 33 figs. 1912.

normally, merely being weighted by a light string tag. When the infested squares fell the date was recorded on the tag. All of the infested squares of a certain weevil were assembled in an inclosed area to prevent damage (fig. 7) and placed on the soil under the plant just as they would normally lie. They were watched daily,

and only about two days before emergence was expected were covered, still under the plant, by coarse wire screen cages (fig. 7) in order to get the number of weevils that emerged and determine the sex. Hence abnormal conditions were experienced for only about 2 days.

Since these records indicated a much longer developmental period than was recorded in previous bulletins, a complete series of control experiments was conducted in the outdoor insectary (fig. 8).

It will be seen by Table VIII that the developmental period



FIG. 6.—The infested squares tagged on the cotton plant, Madison, Fla.

in the tumblers under insectary conditions at Madison is much more rapid than under the most favorable outdoor conditions experienced.

TABLE VIII.—Showing the length of the developmental period of the boll weevil under insectary and field conditions, Madison, Fla., 1918.

Ten-day oviposition period.	In insectary, developmental period.				Outdoors, normal develop- mental period.				Aver- age.
	Number of weevils bred.	Days.			Number of weevils bred.	Days.			Accel- eration of in- sectary days.
		Maxi- mum.	Mini- mum.	Aver- age.		Maxi- mum.	Mini- mum.	Aver- age.	
June 4-13.....	370	15.6	13.6	14.8	50	24.5	20.1	21.6	6.8
July 3-13.....	306	15.2	13.7	14.5	94	24.2	20.8	21.9	7.4
July 31-Aug. 9.....	87	18	14.8	15.8	54	24.3	19.6	23.2	7.4

The development of the weevil is retarded on the plant, and more so on the ground, and accelerated in the insectary. The outside soil is either too hot or too cool and damp, while the insectary maintains a more even condition, warmer than the plant and cooler than the ground.

If one feels of a leaf or square on a hot day he immediately receives a sensation of coolness. If he lays his hand on the sand in the shade of the plant it feels cool and damp, and if he lays the other hand on the sun-heated sand he experiences a sensation of burning.

Dr. Pierce made a series of temperature measurements on June 21, 1919, in a period of less than 2 hours (from 10 to 12 "daylight-saving



FIG. 7.—The field hatchery, Madison, Fla.

time," or 9 to 11 astronomical time) in which the air temperature about 2 feet above the ground was 88.5° to 89.5° F.

The humidity by sling psychrometer was 68.5 to 69 per cent, by wet bulb 73.5 .

The temperature of the sandy soil in the sun was 106.5° , 111° , 111° , and 115° F. at different readings. Once in a while clouds shaded the earth.

In the shade of the cotton plants the temperature of the sandy soil was 92.7° , 93° , and 94° F. at different readings; in other words, the shade of the cotton plant reduced the temperature 14° , but the air temperature was 4° or 5° cooler than the sand under the plant.

Behind the involucre of the square on the plant the temperature was 88° F., and next to the stem of the plant, 2 feet above the ground, it was the same.

When the thermometer was wrapped in cool, green leaves it registered 89° F., but when inserted into a square and wrapped in green leaves it registered 81° .

The thermometer covered one-fourth inch by hot sand in the sun registered 106.5° to 107.5° F.; under one-half inch of sand it registered 99° , under 1 inch 95° , and under $1\frac{1}{2}$ inches of sand 91° .

Thus shallow burial of infested squares would merely give the immature weevils more favorable temperatures and almost insure emergence; while the sun-heated surface soil, even on this moderate day, was heated very close to a fatal temperature.

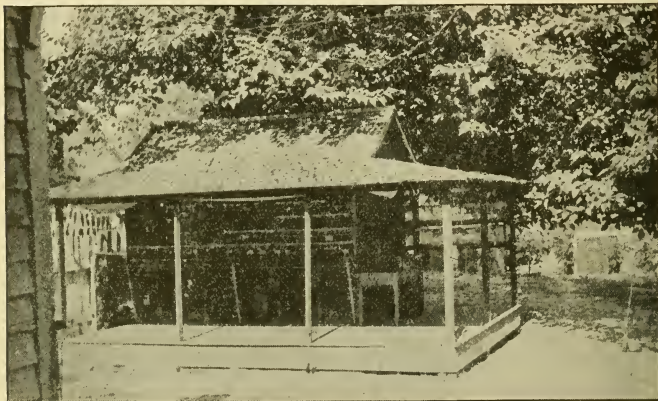


FIG. 8.—Outdoor insectary, Madison, Fla., where the records were secured to check against the field records.

Dr. Pierce then studied the temperature in the field breeding cages and found in the oviposition cage an air temperature of 85° F., a soil temperature in the sun of 108° to 108.5° , in the shade of the wire screen 90° to 94.5° , and in the shade of the plant 92° to 95° . The humidity in the cage was 71.5 per cent, wet bulb 85, while in the open air it was 68.5 per cent, wet bulb 85.5. There is therefore very little difference in the temperature in and out of the cage.

The small wire-screen cages used to cover the squares during the last two days before emergence were then measured. In the shade of the plant the temperature was 94.5° to 96.5° F. and in the sun 103° to 106° . The cage, therefore, serves to mitigate slightly the intense heat.

In the insectary measurements were made in the breeding tumblers. A temperature of 83.5° F. was recorded for the soil in the tumblers, while above the soil the temperature was 86.5° F. Since the tumblers were only moistened once during the hatching period, a temperature

reading on the seventh day gave 84° on the soil and 87° above the soil in the tumblers. On the twelfth day the temperature was 84° on the soil and 86.5° above the soil. Thus, on this particular day, weevils developing in squares on the plant were experiencing 88° F., or probably less, and those in the squares which had fallen on the ground were receiving from 92° to 115° F., according to whether they were shaded or exposed to the sun, while weevils in the insectary were faring well at 83.5° to 87° F. It has been shown that the most favorable temperature for development is between 83° and 84° F.

In order completely to check up conditions maximum and minimum thermometers were installed in the field hatchery. Thus the maximum and minimum temperatures experienced by the weevils after the falling of the infested square (fig. 9) were measured.



FIG. 9.—Thermometers installed underneath the cotton plants in the field to secure soil temperature, Madison, Fla.

EGG-LAYING ACTIVITY OF HIBERNATED FEMALE WEEVILS UNDER FIELD CONDITIONS.

Table IX gives the data on the egg-laying activities of female weevils under field conditions on upland cotton squares. The females deposited an average of 76 eggs each at a rate of 8.4 eggs per day. The maximum number of eggs during any one day was 19. It is practically impossible to keep a continuous record of female weevils

under field conditions. Female weevils liberated in large cages over growing cotton plants frequently get killed accidentally, spiders sometimes catch them, and they escape very readily from the cages. The records presented in Table XI really indicate the rate of oviposition per day instead of the average number of eggs deposited per female.

TABLE IX.—*Egg-laying activity of individual hibernated female boll weevils kept with males under field conditions on upland cotton.*

Parent weevil.		Date of first egg.	Date of last egg.	Total number of eggs deposited.	Average number of eggs per day.	Maximum number of eggs per day.	Source of weevils.
Generation.	No.						
Hibernated.....	A 1	May 29	June 1	28	7	8	Hibernated field collected.
Do.....	A 2	..do....	June 21	218	9.9	19	Do.
Do.....	A 3	May 31	June 5	33	5.5	7	Do.
Do.....	A 4	June 1	June 14	80	6.1	9	Do.
Do.....	A 5	..do....	June 8	65	9.3	18	Do.
Do.....	A 7	June 8	June 15	63	7.9	13	Do.
Do.....	A 8	June 9	June 13	49	9.8	13	Do.
Do.....	A 9	June 8	June 14	68	9.7	14	Do.
Do.....	A 10	..do....	June 19	70	5.8	11	Do.
Do.....	A 13	June 12	June 21	88	11	19	Do.
Do.....	A 14	..do....	June 23	97	8.1	19	Do.
Do.....	A 16	June 18	June 22	54	10.8	18	Do.
Total.....				913		168	
Average.....				76	8.4		
Maximum.....				218	11	19	
Minimum.....				33	5.5		

LENGTH OF TIME UPLAND COTTON SQUARES HANG ON THE PLANTS AFTER EGG PUNCTURE.

In Table X are found the data on the length of time squares hang on the plants after egg puncture by the weevil. The average number of days from the time the egg is deposited until it drops off the plant is shown to be 11.5 days. The maximum length of time any square hung on the plant after egg puncture was 19 days and the minimum period 6 days.

The length of time elapsing from the date of falling of the infested square from the cotton plant to the emergence of the adult weevil is shown to be 10.8 days. Practically one-half of the weevil's immature stage is developed while the square is on the plant. The minimum number of days from falling of the infested square to the emergence of the adult weevil was 3 days and the maximum number 19 days.

TABLE X.—*Showing development of weevil as related to the length of time squares hung on plants after egg puncture, eggs deposited by hibernated females on upland cotton.*

Date oviposition began.	Total number squares under observation.	Total number days on plant after puncture.	Minimum number days on plant after puncture.	Maximum number days on plant after puncture.	Average number days from puncture to falling of square.	Total number squares under observation.	Total number days from falling to adult.	Minimum number days from falling to adult.	Maximum number days from falling to adult.	Average number days from falling of square to adult.
May 29.....	29	315	7	15	11.6	12	122	7	12	10.1
May 27.....	100	1,125	6	18	11.2	17	185	7	15	10.8
May 31.....	24	269	8	16	11.2	9	82	7	11	9.1
June 1.....	33	400	6	17	12.1	11	108	3	13	9.8
Do.....	24	307	10	19	12.7	2	21	10	11	10.5
June 8.....	23	265	7	17	10.6	7	79	7	16	11.2
June 9.....	12	148	6	15	12.3	2	22	10	12	11
June 8.....	42	482	7	19	11.4	9	105	9	16	11.6
Do.....	51	514	7	13	10.7	8	107	10	16	13.3
June 12.....	28	289	6	16	10.3	14	156	9	19	11.1
Do.....	36	410	6	16	11.3	7	83	10	15	11.8
June 18.....	19	240	9	19	13.6	4	39	9	11	9.7
Total.....	421	4,764	85	200	-----	102	1,109	98	167	-----
Average.....	-----	-----	7.08	16.6	11.5	8.5	-----	8.1	13.9	10.8
Maximum.....	-----	-----	10	19	13.6	17	-----	10	19	13.3
Minimum.....	-----	-----	6	13	10.3	4	-----	3	11	9.1

FECUNDITY RECORDS OF HIBERNATED FEMALE BOLL WEEVILS ON UPLAND COTTON UNDER FIELD CONDITIONS.

The data on the fecundity of hibernated female weevils under field conditions are presented in Table XI. Of the progeny produced by the individual female weevils 73 males required 1,536 weevil days, or an average period of 21.7 days, for development from egg to adult. A total of 52 female weevils required 1,145 weevil days, or an average period of 20.2 days, for development of the immature stage. The average period of development for both sexes under actual field conditions was 21.7 days, with a maximum of 24 and a minimum of 19.5 days for the first-generation weevils. A total of 17.99 per cent of the infested squares produced adult weevils. This percentage is remarkably low compared with the generally accepted belief that approximately 35 per cent of the infested squares produced adults. At Madison the Norfolk sandy soil is so well drained that the developing weevils are exposed to terrific heat during the time the square is on the soil before the adult weevils emerge. Consequently a very large mortality occurs among the immature stages of the weevil.

TABLE XI.—*Fecundity record of individual hibernated females of the boll weevil fertilized in spring under field conditions on upland cotton.*

Date oviposition began.	Number eggs deposited normally.	Progeny produced by individual females.									Percentage punctured squares producing adults.
		Males.			Females.			Both sexes.			
		Weevils bred.	Weevil days.	Developmental period.	Weevils bred.	Weevil days.	Developmental period.	Total weevils bred.	Total weevil days.	Period both sexes.	
				Days.			Days.			Days.	
May 29.....	28	10	188	20.8	6	124	20.6	16	312	19.5	57.1
Do.....	218	15	297	21.2	7	148	21.1	22	445	20.2	10.08
May 31.....	33	7	137	19.6	3	60	20	10	197	19.7	30.3
June 1.....	80	4	93	23.2	7	166	23.3	11	259	23.5	13.7
Do.....	65	2	43	21.5	0	0	0	2	43	21.5	13.07
June 8.....	63	6	132	22	4	92	23	10	224	22.4	15.8
June 9.....	49	1	22	22	1	23	23	2	45	22.5	4.08
June 8.....	68	7	170	24.2	3	70	23.3	10	240	24	14.7
Do.....	70	6	125	20.8	7	152	21.7	13	277	21.3	18.5
June 12.....	88	5	120	24	3	67	22.3	8	187	23.3	11.4
Do.....	97	5	104	20.8	7	152	21.7	12	256	21.3	13.6
June 18.....	54	5	105	21	4	91	22.7	9	196	21.7	13.6
Total.....	913	73	1,536		52	1,145		125	2,681		
Average.....	76.08			21.7			20.2			21.7	17.99
Maximum.....	218	15		24.2	7		23.3	22		24	57.1
Minimum.....	28	1		19.6	0		0	2		19.5	4.08

SUMMARY OF THE DEVELOPMENTAL PERIOD OF THE FIRST-GENERATION BOLL WEEVILS IN UPLAND COTTON SQUARES UNDER FIELD CONDITIONS.

Table XII gives a summary of the period of development in upland cotton squares of first-generation weevils under field conditions, together with the temperature and humidity records. The average period of development in the infested squares while the squares remained on the growing cotton plants is shown to be 10.9 days. During the time the infested squares were on the ground or after they had dropped off the plant the average period of development is shown to be 11.4 days. The average maximum soil temperature was 103.7° F. Since it has been demonstrated that the boll weevil develops most rapidly under a mean temperature of 84° F., the higher temperatures experienced while the square is on the soil retard the developing process and prolong the developmental period of the weevil. Also high soil temperatures are directly responsible for the death of large numbers of immature weevils. At Madison it was observed that a very high percentage of teneral weevils was killed by the heat before the weevils could make an emergence hole in the square.

TABLE XII.—*Summary of development of first generation boll weevils under field conditions on upland cotton.*

Date of oviposition.	Dates squares dropped off.	Date hatched.	Total number weevils bred.		Average period of development.			Mean air humidity.	Mean soil temperature.	Average maximum soil temperature.
			Male.	Female.	On plant.	On ground.	Total.			
					<i>Days.</i>	<i>Days.</i>	<i>Days.</i>			
May 29-June 1...	June 6-June 25.	June 17-June 25.	8	6	11.6	10.1	21.7	65.5	85.4	111.7
May 29-June 21...	June 7-July 8...	June 12-July 10.	15	7	11.2	10.8	22	72.2	82.3	101.6
May 29-June 5...	June 9-June 16.	June 20-June 25.	7	3	10.8	9.4	21.2	65.2	85.5	109.7
June 1-June 14...	June 11-June 24	June 20-July 5...	8	3	11.2	12.7	23.5	76.3	81	101.6
June 2-June 8...	June 11-June 23	June 22-June 25.	2	0	11	10.5	21.5	62.5	85.5	109.7
June 8-June 15...	June 16-June 30	June 30-July 5...	5	4	10.1	12.2	22.3	76.3	81	101.6
June 9 to June 13.	June 18-June 23	July 2-July 5...	1	3	11.5	11.0	22.5	76.3	81	101.6
June 6-June 14...	June 17-July 1...	July 3-July 9...	7	3	10.3	13.7	24	75.96	81.4	101.3
June 8-June 19...	June 16-June 30	July 1-July 5...	5	4	10.4	13.3	23.7	76.3	81	101.6
June 12-June 21...	June 18-July 4...	July 5-July 10...	6	7	9.3	12	21.3	77.2	82.3	101.6
June 12-June 23...	June 19-July 8...	July 2-July 13...	5	7	12	11.8	23.8	79.2	82.8	101.2
June 18-June 22...	June 30-July 8...	July 11-July 13.	4	5	12.5	9.4	21.9	79.2	82.8	101.2
Total.....	.....	.....	73	52	.....	.....	.....	.....	.....	.....
Weighted average.	.....	.....	.....	.....	10.9	11.4	22.4	73.51	82.6	103.7

DEVELOPMENTAL PERIOD OF FIRST GENERATION BOLL WEEVILS ON SHORT STAPLE UPLAND, SEA-ISLAND, AND LONG-STAPLE UPLAND COTTONS UNDER FIELD CONDITIONS.

In addition to the series of hibernated female weevils under observation a series of first generation weevils was used to determine the difference in the length of the developmental period under field conditions on upland, sea-island, and long-staple cottons.

The first generation female weevils deposited eggs at an average rate of 7.6 eggs per day on sea-island cotton. The maximum number of eggs deposited during any one day in sea-island cotton squares was 29.

The 10 female weevils under observation on long-staple cotton squares deposited eggs at an average rate of 6.3 eggs per day. The greatest number of eggs deposited during one day in long-staple squares was 21 eggs.

On upland cotton the 10 female weevils deposited eggs at an average rate of 6.2 eggs per day, with a maximum of 23 eggs deposited by a single female during one day.

On upland cotton the infested squares remained on the plants for an average period of 10.9 days. A period of 11.4 days was the average time required to complete the development of the immature stages after infested squares dropped off the plant.

The average number of days elapsing from the date of egg puncture to the falling of the infested squares was 10.7 on sea-island cotton. The average number of days required to complete the de-

velopment of the immature weevil after the sea-island squares dropped off the plant was 10.4.

The infested squares on the long-staple cotton required 12.3 days from the date of the egg puncture to the falling of the infested square. The time required for the immature weevil stages to complete their development after the long-staple squares dropped off the cotton plants averaged 10.5 days. One of the objections to the long-staple varieties of cotton is the tendency of the infested squares to hang on the plants, protecting the immature weevil stages to a certain extent from natural enemies and mechanical injury.

A total of 92 male weevils of the first generation bred in sea-island cotton squares required 2,006 weevil days or an average period of



FIG. 10.—Shallow wooden troughs filled with crude oil to keep ants out of the weevil hatchery, Madison, Fla.

21.8 days for development of the immature stage. The 75 female weevils bred from the same source required a total of 1,651 weevil days or an average period of 22 days for development from egg to adult. An average period of 21.9 days was required for the development of both sexes of the first-generation weevils in sea-island cotton squares.

The 35 male weevils bred from long-staple cotton squares required a total of 726 weevil days or an average period of 20.7 days from egg to adult. A total of 549 weevil days was required for the development of the 26 female weevils from long-staple cotton squares, or an average of 21.8 days. The developmental period in long-staple cotton squares for both sexes from egg to adult averaged 20.9 days.

A total of 61 male weevils of the first generation bred in upland cotton squares under field conditions required 1,344 weevil days, or an average period of development of 22 days. The 33 female weevils

of the same series required 718 weevil days, or an average developmental period from egg to adult of 21.8 days. The developmental period for both sexes under field conditions averaged 21.1 days from egg to adult.

The total percentage of the infested squares producing adult weevils could not be determined, as a considerable number of the infested squares under observation were destroyed by ants, *Solenopsis* sp. (fig. 10).

COMPARISON OF THE DEVELOPMENTAL PERIOD OF THE IMMATURE STAGES OF THE BOLL WEEVIL UNDER FIELD AND INSECTARY CONDITIONS.

The results of the breeding experiments under outdoor insectary conditions, conducted primarily to check the field breeding records, are tabulated and summarized in Table XIII. The average developmental period under insectary conditions for the hibernated and first-generation weevils in upland cotton squares was 14.5 days. The developmental period of the progeny produced by first generation weevils in long-staple upland and sea-island cottons was 14.2 and 13.7 days, respectively. There is little if any difference in the length of the developmental period of the weevils bred in the three types of cotton squares under insectary conditions. A total of 1,148 weevils which required 16,568 weevil days or an average period of 14.3 days for development under insectary conditions is recorded for the three types of cotton.

The developmental period of the immature stage of the boll weevil under normal field conditions on short-staple upland, long-staple upland, and sea-island cottons is presented in Table XIV. The male weevils bred in upland cotton squares required 21.7 days for development from egg to adult and the females of the same series required a slightly longer period—22.33 days. A total of 323 weevils bred in upland cotton squares under normal field conditions required an average period of 21.9 days for development from the time the egg was deposited to emergence of the adult weevil.

In sea-island cotton squares 92 male weevils required 2,006 weevil days, or an average period of 21.8 days, for development from egg to adult. The 75 female weevils bred from the same source required 1,651 weevil days or an average period of development of 22 days. Both sexes required an average developmental period of 21.9 days from egg to adult.

On long-staple upland cotton 35 male weevils bred in squares under field conditions required 726 weevil days or an average period of 20.7 days for development of the immature stages. The 26 female weevils required 549 weevil days or an average period of 21.8 days for development. Both sexes bred in long-staple upland cotton squares required an average period of development of 20.9 days from egg to adult.

The 551 weevils bred under field conditions from squares of all three types of cotton required a total of 12,012 weevil days or an average period of development of 21.8 days from egg to adult.

The average developmental period of the weevil in all three types of cotton squares under insectary conditions is shown in Table XIII to be 14.3 days from egg to adult. The average developmental period under normal field conditions for weevils bred from all three types of squares is shown to be 21.8 days. Under actual field conditions it is safe to say the boll weevil requires a period of 7.5 days additional time for development, or fully one-half more time than is required under insectary conditions at Madison, Fla.

TABLE XIII.—*Table showing the developmental period of the boll weevil under insectary conditions, 1919.*

Nature of weevils.	Larval food.	Period of oviposition.	Number of males bred.	Male weevil days.	Average period.	Number of females bred.	Female weevil days.	Average period.	Total number of weevils bred.	Total weevil days.	Average period.
Hibernated.....	Upland cotton squares.	June 5-July 25	247	3,692	Days 14.9	123	1,816	Days 14.7	370	5,508	Days 14.8
First generation.....	.....	July 5-Aug. 19	189	2,765	14.6	117	1,762	14.3	306	4,438	14.5
Total upland cotton.....	.....	.....	436	6,457	14.8	240	3,578	14.5	676	9,946	14.7
Long-staple cotton: First generation...	Long-staple squares.	July 9-Aug. 2	210	2,953	14.06	154	2,187	14.2	364	5,140	14.1
Sea-island cotton: First generation...	Sea-island squares.	July 5-Aug. 9	67	917	13.6	41	565	13.7	108	1,482	13.7
Total all cotton.....	.....	.....	713	10,327	14.15	435	6,330	14.1	1,148	16,568	14.3

TABLE XIV.—*Showing the total developmental period of the boll weevil under field conditions.*

Nature of weevils.	Larval food.	Period of oviposition.	Males.			Females.			Both sexes.		
			Number of males bred.	Number of male weevil days.	Average period.	Number of females bred.	Female weevil days.	Average period.	Total number bred.	Total weevil days.	Average period both sexes.
Upland cotton:					Days			Days			Days
Hibernated.....	Cotton sq...	May 29-June 13.	73	1,536	20.9	52	1,145	22.01	125	2,681	20.8
Do.....	do.....	June 7-June 22.	23	477	20.7	27	607	22.5	50	1,084	21.6
First generation...	do.....	July 3-Aug. 2...	61	1,344	22	33	718	21.8	94	2,062	21.9
Second generation.	do.....	July 31-Aug. 22.	23	539	23.4	31	714	23.03	54	1,253	23.2
Total upland cotton.....	.....	.....	180	3,896	21.7	143	3,184	22.33	323	7,080	21.9
Sea-island cotton:											
First generation...	Cotton sq...	June 26-Aug. 4.	92	2,006	21.8	75	1,651	22	167	3,657	21.9
Long-staple cotton:											
First generation...	do.....	June 30-July 30.	35	726	20.7	26	549	21.8	61	1,275	20.9
Total all three types of cotton.	.....	.....	307	6,628	21.4	244	5,384	22.06	551	12,012	21.8

DEVELOPMENTAL PERIOD OF THE BOLL WEEVIL IN GREEN COTTON BOLLS.

Owing to the fact that large numbers of adult weevils in the field at the time the bolls are set deposit eggs in the bolls almost as readily as they do in the squares, it is almost impossible to secure noninfested bolls for breeding purposes. Therefore the following method for securing the developmental period of the weevil in cotton bolls for upland, long-staple, and sea-island cotton was followed.

Large, healthy, grown bolls were examined for egg punctures. The number of egg punctures was recorded on a light string tag, together



FIG. 11.—Green cotton bolls bagged in muslin to secure records on the immature stages of the weevil, Madison, Fla.

with the date of examination. The boll was inclosed in a thin muslin bag to prevent further infestation and allowed to remain on the plant under normal field conditions until the adult weevil emerged. All weevils that emerged were counted and the sex determined.

During the month of August 200 weevil-infested bolls were bagged (fig. 11) on each of the three types of cotton. Daily examinations were made of the bagged bolls after a period of 10 days had elapsed.

The upland cotton bolls produced 7 male weevils that required 233 weevil days for development, or an average period of 33.2 days. The 6 female weevils bred from upland cotton bolls required a total of 207 weevil days, or an average period of 34.5 days from egg to adult.

The 200 long-staple or thick-rind cotton bolls produced 8 male weevils that required 250 weevil days from egg to adult, or an average

period of 31.2 days. A total of 298 weevil days was required by the 10 female weevils bred from long-staple cotton bolls, or an average period of 29.8 days from egg to adult. The sea-island cotton bolls produced 30 male weevils that required 953 weevil days from egg to adult, or an average developmental period of 31.7 days. A total of 18 female weevils bred required 623 weevil days, or an average period of 34.6 days for development from egg to adult. (Fig. 12.)



FIG. 12.—Four cavities in which four boll weevils were reared in a sea-island cotton boll, Madison, Fla.

Since the bolls had probably been punctured from 5 to 7 days before they were bagged, it is evident that the developmental period of the boll weevil in green cotton bolls is approximately 35 to 40 days under the most favorable summer temperatures and longer during the fall months. Howe⁹ states that the developmental period of the boll weevil in green upland cotton bolls at Tallulah, La., under insectary conditions, was 16.2 days. At Madison, Fla., the developmental period of the boll weevil in green cotton bolls under actual field conditions more than doubles Howe's record.

FECUNDITY OF THE BOLL WEEVIL IN UPLAND AND SEA-ISLAND COTTON BOLLS.

Throughout the season of 1918 attempts were made to secure records of the fecundity of the weevil in green cotton bolls. More than 200 pairs of weevils were under observation at different times during the season. In no case were clear and concise records secured for individual weevils. For some peculiar reason the females did not oviposit freely in the green cotton bolls under insectary conditions.

PREFERENCE SHOWN BY FEMALE WEEVILS FOR OVIPOSITION IN SEA-ISLAND AND UPLAND COTTON FRUIT.

An experiment to determine the preference by the boll weevil for deposition was made by confining six female weevils over upland and sea-island cotton fruit. The female weevils were confined in a large battery jar on moist sand. Fresh squares and bolls of both sea-island and upland cottons were placed in the jar each morning

⁹ Howe, R. W. Studies of the Mexican Cotton Boll Weevil in the Mississippi Valley, U. S. Dept. Agr. Bul. 358, p. 28. 1916.



FIG. 1.—SHOWING POSITION OF EGG PUNCTURES ON SEA-ISLAND COTTON.



FIG. 2.—SHOWING POSITION OF EGG PUNCTURES ON UPLAND COTTON.



FIG. 3.—THE DIFFERENCE IN STRUCTURE BETWEEN SEA-ISLAND COTTON BOLLS (ABOVE) AND UPLAND COTTON BOLLS (BELOW).

THE BOLL WEEVIL ON SEA-ISLAND AND UPLAND COTTONS.

and all fruit in which eggs had been deposited was recorded and removed from the jar. The records of the experiment are presented in Table XV. A total of 49 eggs were deposited in upland squares compared with 17 eggs deposited in sea-island cotton squares. Eggs were deposited in six sea-island bolls, but in none of the upland cotton bolls.

TABLE XV.—*Preference shown by females of the boll weevil in locations for oviposition on sea-island and upland cotton, Madison, Fla., 1918.*

Date.	Eggs in—			
	Upland squares.	Sea-island squares.	Upland bolls.	Sea-island bolls.
July 17.....	0	0	0	3
July 18.....	0	0	0	1
July 19.....	5	0	0	2
July 20.....	3	0	0	0
July 21.....	9	4	0	0
July 22.....	3	2	0	0
July 23.....	6	3	0	0
July 24.....	2	2	0	0
July 25.....	4	3	0	0
July 26.....	5	0	0	0
July 27.....	3	1	0	0
July 29.....	4	2	0	0
July 31.....	5	0	0	0
Total.....	49	17	0	6

COMPARISON OF THE NUMBER OF BOLL WEEVILS THAT EMERGE FROM UPLAND AND SEA-ISLAND SQUARES AND BOLLS.

The writer placed 4,000 upland squares in a large wire-screen cage on August 26, 1918. The squares were carefully examined to determine whether each square was punctured and large enough to support the developing weevil larva. Similarly, 4,000 sea-island squares were put up on the same date.

From the 4,000 upland squares 1,476 adult weevils emerged soon after the squares were placed in the large cage, or a percentage of 36.9. From the sea-island squares 1,979 weevils, or a percentage of 49.4, emerged.

One thousand five hundred upland and 1,500 sea-island bolls were placed in a large wire-screen cage on September 1, 1918, to determine whether more weevils would hatch from sea-island than from upland bolls. It is shown in Plate I that there is a decided difference in structure between the two types of bolls, the sea-island being oblong, with a soft and oily texture. One hundred weevils hatched from the upland bolls compared to 650 weevils from the sea-island-cotton bolls.

From the records secured at Madison, Fla., during 1918, it appeared that the majority of egg punctures in sea-island bolls produced adult boll weevils. It not infrequently happened that as many as from four to eight weevil larvæ would complete their life cycle in a single boll.

THE RELATION OF TEMPERATURE TO THE BIOLOGY OF THE BOLL WEEVIL.

The relationship of temperature to the biology of the weevil has been thoroughly studied for the adult weevil. Little information is available, however, showing the effect of temperature on the immature stages of the weevil. For years the Bureau of Entomology has made so-called status examinations in different parts of the weevil-infested area of the cotton belt to determine the percentage of mortality caused by the heat and dry weather in the immature stages of the weevil. From an examination of 91,082 immature weevil stages Hunter and Pierce¹⁰ found 23.8 per cent killed by heat and dryness. This examination extended over the different months of the growing season from May to October. The relatively small percentage of mortality among the immature weevil stages recorded in this examination is misleading, because the life of the immature weevils was not followed through until the weevil became adult. From the writer's observations at Madison, Fla., the critical period of the immature weevil caused by intense heat seems to extend to the teneral adult stage. Hundreds of teneral adult weevils were observed in squares in the field hatchery that were killed by the heat before they could make an emergence hole in the square. Therefore an examination made to determine the percentage of mortality caused by heat and dryness on any given date is misleading for the simple reason that, although the percentage of immature stages dead may not run very high at the time of examination, yet if it were possible to follow these stages through to emergence of the adult weevil the figures might be trebled. As a concrete illustration, on June 25, 1919, Dr. Pierce examined 451 weevil stages in fallen brown squares taken from plants on which tagged squares were hanging or had fallen. Of the 451 stages examined 134, or a percentage of 38.95, had been killed from climatic causes. At the time this examination was made the writer had 1,378 fallen punctured squares that were tagged on the day of egg-puncture under observation for breeding records. Dr. Pierce's examination indicated that 38.95 per cent of the 1,378 fallen punctured squares would not hatch weevils, since the punctured squares used in his examination were taken from underneath the plants where tagged squares belonging to the writer were lying. However, of the 1,378 squares that were tagged, only 134, or 9.7 per cent, produced adult weevils. It is evident that a field examination is misleading in so far as the percentage of control of the immature weevil stages by heat and dryness is concerned unless these stages can be followed through to the emergence of the adult weevil.

¹⁰ Hunter, W. D., and Pierce, W. D., *op. cit.*

TEMPERATURES FATAL TO THE IMMATURE STAGES OF THE BOLL WEEVIL

Owing to the lack of proper soil thermometers, it was impossible to determine accurately the fatal temperatures for the immature stages of the weevil. The thermometers in use frequently recorded maximums of 115 to 125° F., and under these maximum soil temperatures it seems safe to assume that not more than 10 per cent of the immature weevils will survive on Norfolk sandy soils such as occur at Madison, Fla.

THE EFFECT OF TEMPERATURE ON THE LENGTH OF THE DEVELOPMENTAL PERIOD OF THE IMMATURE STAGES OF THE BOLL WEEVIL.

Mean temperature and humidity either shorten or prolong the developmental period of the immature weevil. The exact amount of humidity required for development under optimum conditions has never been determined. A mean temperature of 84° F. has been determined as the optimum temperature for development of the immature weevil stages. Were it possible for the immature weevil to have the exact amount of humidity and a mean temperature of 84°, the developmental period of the immature stages would be approximately 8 days. Temperature and humidity, however, are never just in the right proportion and so the period of development varies under different conditions.

THE EFFECT OF TEMPERATURE ON THE LENGTH OF THE DEVELOPMENTAL PERIOD UNDER INSECTARY CONDITIONS.

Under insectary conditions the development of the weevil has been shown to be approximately 14.3 days from egg to adult. This period of development is much shorter than the period under field conditions owing to the smaller variation in extremes of temperature. The mean temperature at Madison, Fla., under insectary conditions during the months of June, July, and August approximates 81° F. according to the United States Weather Bureau records. The average mean temperature is lower by 3° than is required for the optimum developmental conditions. Therefore it is to be expected that the developmental period would be approximately 14 days under insectary conditions.

THE EFFECT OF TEMPERATURE ON THE DEVELOPMENT OF THE IMMATURE STAGES OF THE WEEVIL UNDER FIELD CONDITIONS.

Under field conditions the development of the immature weevil is considerably retarded and prolonged. It has been shown that the infested squares remain on the plants for approximately 11 days after egg puncture. For fully 8 days after egg puncture the sap continues to flow to the injured squares and keeps the temperature lower than is required for proper weevil development. At night the

transpiration of the plant further lowers the temperature surrounding the developing weevil, and for 12 of the 24 hours of the day the minimum temperatures below 84° F. are retarding and prolonging the developmental period. After the infested square drops off the plant it is exposed to the high soil temperatures which range well above 100° F. from 10 a. m. to 5 p. m. The immature weevil is again retarded and all temperatures above 84° F. as well as below 84° F. act as retarding factors.

THE DEVELOPMENTAL PERIOD OF THE BOLL WEEVIL ON DIFFERENT TYPES OF SOIL.

Although the field biology of the boll weevil has not been studied for the different types of soil, the results secured at Madison, Fla., indicate certain generalizations which will probably hold good for the majority of cases.

In addition to heat and dryness soil drainage must be considered. Poorly drained soils such as are found in the Mississippi Delta and the swamps and river bottoms will probably show an average period of development from egg to adult to be a few days shorter than it would be were these soils well drained. On the other hand sandy, well-drained soils, such as the Gulf Coastal Plains, the oak, hickory, and pine uplands, and the rocky hillside types, will probably show a longer period of development than any other generalized type of soil. The semiarid region of Texas should show the longest period of weevil development under field conditions. The range in the developmental period at Madison, Fla., was from 16 to 38 days for weevils developing in squares and it appears probable that the maximum period would be much greater in the dry regions of Texas.

THE EFFECT OF THE DETERMINATE GROWTH OF THE COTTON PLANT ON THE BIOLOGY OF THE BOLL WEEVIL.

Perhaps no single factor contributes so much to the control of the weevil as the determinate growth of the cotton plant. On the Gulf Coastal Plains type of soil at Madison, Fla., the upland cotton usually sets its crop by the 20th of July and the cotton is practically all open by the 20th of August. In addition, the cotton plants are usually attacked by several species of rusts and wilts, which result in the plant becoming decadent, shedding off the leaves, squares, and immature bolls. This leaves the weevil with few breeding places. At this particular time also the weevils are so numerous in the cotton fields that the few squares growing on the plants are subjected to an overwhelming attack for both food and breeding purposes, which results disastrously to the fall generations of the boll weevil. The adult weevils in the field rapidly die off, and as few weevils are

hatching out the number that live to enter hibernation is greatly decreased. The cessation of squaring naturally forces a considerable number of weevils to attack bolls which otherwise might escape. Whether the loss resulting from this attack is offset by an advantage to the crop of the next season on account of the presence of fewer hibernated weevils has not been fully determined.

THE MAXIMUM NUMBER OF GENERATIONS OF THE BOLL WEEVIL UNDER FIELD CONDITIONS.

The number of generations of the boll weevil under field conditions varies with the different seasons and on the different types of soil. A very dry and hot season may affect either generation to such an extent that the eggs deposited during the first half of the generation may not produce weevils at all, and consequently the generation is much prolonged. The following table shows the maximum number of generations at Madison, Fla., under field conditions:

TABLE XVI.—*Maximum number of generations of the boll weevil bred in cotton squares, Madison, Fla.*

Generation.	Date.	Period from maturity to maturity.	Generation.	Date.	Period from maturity to maturity.
		<i>Days.</i>			<i>Days.</i>
First generation:			Fourth generation:		
Eggs deposited.....	June 1	.....	Eggs deposited.....	Aug. 24	.....
Generation mature.....	June 22	.....	Generation mature.....	Sept. 16	30
Second generation:			Fifth generation:		
Eggs deposited.....	June 30	.....	Eggs deposited.....	Sept. 23	.....
Generation mature.....	July 20	29	Generation mature.....	Oct. 16	32
Third generation:			Sixth generation:		
Eggs deposited.....	July 28	.....	Eggs deposited.....	Oct. 24	.....
Generation mature.....	Aug. 17	29	Generation mature.....	Nov. 17	33

The average date of killing frost at Madison, Fla., according to the 10-year average of the United States Weather Bureau, is November 29, therefore only six generations of weevils could develop under field conditions.

HIBERNATION OF THE BOLL WEEVIL IN FLORIDA.

During the winter of 1918-19 three series of hibernation experiments were conducted to determine the percentage of weevils surviving the winter at Madison, Fla. The experiments were arranged to secure data on the number of weevils surviving the winter in the open fields and along ditch banks, in the woods on the ground among the leaves and other rubbish, and in the moss covered trees in the woods (figs. 13, 14, 15).

Large wire screen cages 3 by 3 feet by 4 feet high were used for the hibernation experiments. The cages in the fields and on the ground in the woods were filled with an equal amount of moss, leaves, and cornstalks to represent approximately the material the weevils would hibernate in under normal conditions. The cages installed

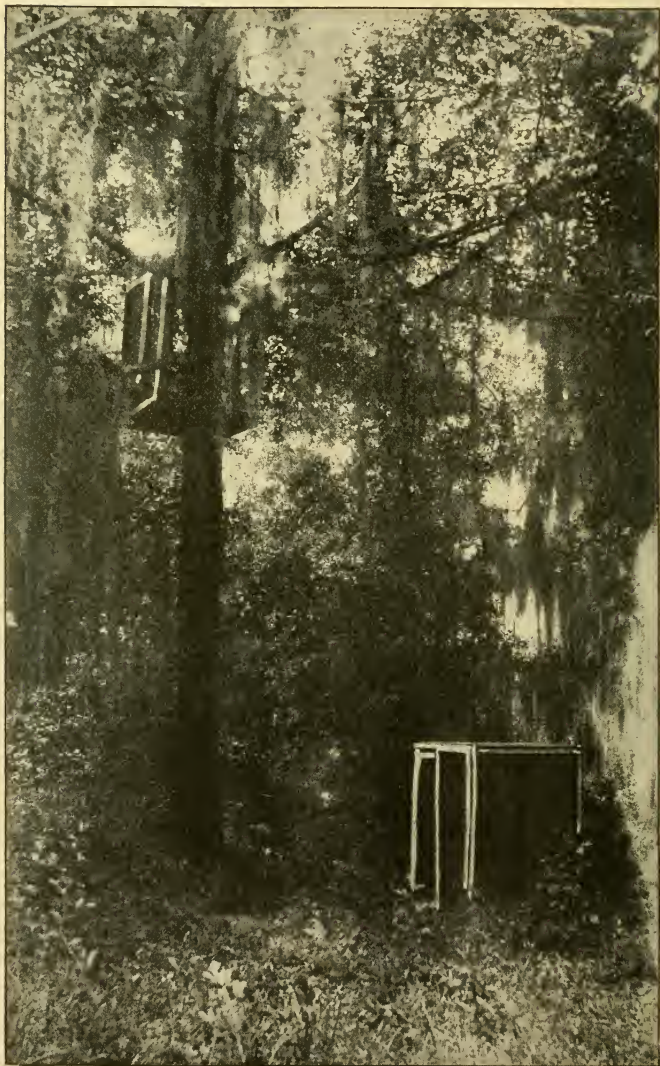


FIG. 13.—Hibernation cages on the ground in the woods, Madison, Fla.

in the trees were supplied with moss only and averaged 10 feet above the surface of the ground (fig. 15).

The boll weevils were collected from near-by cotton fields and installed in the cages every two weeks, beginning on October 1, the last cages being installed on December 1.

TIME OF ENTRANCE INTO HIBERNATION.

The time of entrance into hibernation by the boll weevil at Madison, Fla., usually begins about the time of the first killing frost. The average date of this event is November 29. During the fall of



FIG. 14.—Hibernation cages in the open field at Madison, Fla.

1918, however, the warm weather held on until about December 8. On November 13 the temperature dropped to 37° F., but the 20 days following this drop were extremely warm and all weevils seemed active until the drop in temperature on December 8. The weevils were in hibernation almost continuously until February 20, the date on which the emergence records were started. The mean temperature for November was 59.1° F. and 56.4° F. for December. When it is considered that hibernation begins between mean temperatures of 56 and 60° F. it is seen that the hibernation of the weevil in Florida during November and December is more of a drowsy condition than one of inactivity. The mean temperature for January, 1919, was 46.6° F. and for February 61.9° F. Therefore the weevil really entered hibernation late in December and remained in this condition for the month of January.

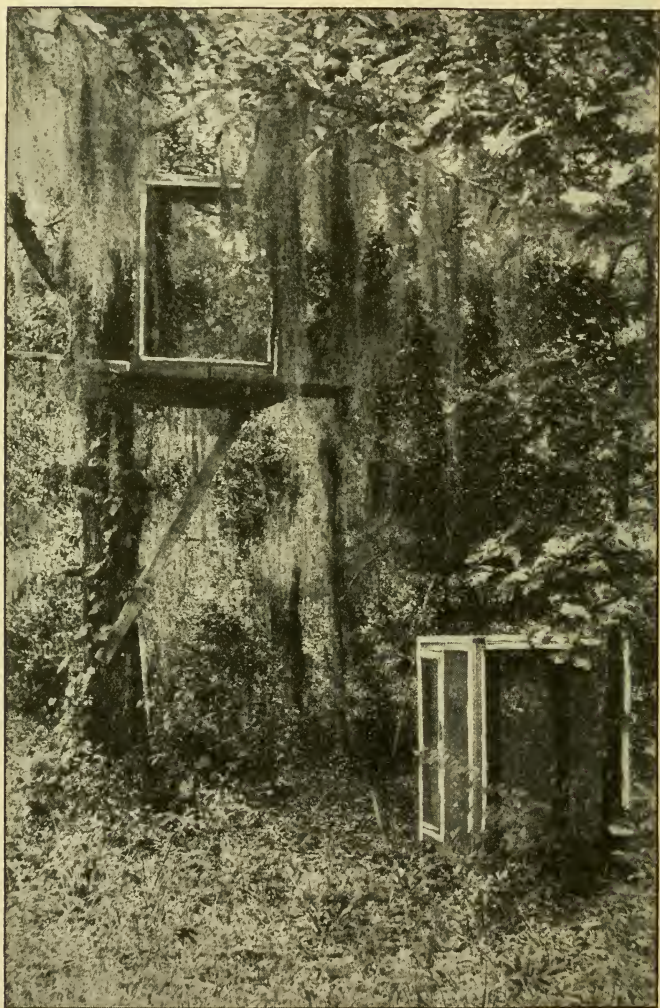


FIG. 15.—Hibernation cages 10 feet above ground in the trees at Madison, Fla.

ACTIVITY DURING THE HIBERNATION PERIOD.

In northern Florida the boll weevil, during the period of hibernation, is seldom inactive for a period of time longer than a month. As was pointed out, the only months in which the average mean temperature is below 56° F. are December and January, and even then it not infrequently happens that warm days occur such as would force the weevil to activity. Thus it might be said that the hibernation of the boll weevil in northern Florida is incomplete.

TIME OF EMERGENCE FROM HIBERNATION.

Owing to the incomplete hibernation of the boll weevil in northern Florida the time of emergence must necessarily be a variable date. February 20 has been selected as the date emergence started in the experimental work at Madison. However, six weevils emerged on the 10th of February and four on the 16th. After February 20 little cold weather is experienced at Madison, and this date may be safely assumed to represent approximately the date when emergence begins for weevils sheltered in places exposed to the direct rays of sunlight.

RATE OF EMERGENCE OF HIBERNATED WEEVILS IN FLORIDA.

The emergence period in Florida extended over the period from February 20 to July 7. The rate of emergence was decidedly more gradual than might be expected when the relatively high temperatures prevailing during March, April, and May are considered. The accompanying diagram (fig. 16) shows the daily rate of emergence of the weevil when hibernating in the open fields, on the ground in the woods, and in the moss on the trees 10 feet above ground. The diagram also shows three prominent periods of emergence, or rather accelerations in the rate of emergence—viz, March 3, April 4, and May 5, 6, and 7. On these dates the rainfall varied from 0.1 of an inch on March 3 to 1.75 inches on May 7. The extreme emergence recorded for May 6, 7, and 8 was also probably influenced by excessive temperatures. In the accompanying chart (fig. 17) the total percentage of rainfall compared to the total percentage of weevils emerged at different dates also indicates that excessive temperature was operating along with the rainfall after the 6th of May.

One of the interesting facts concerning the daily emergence of the weevil when hibernating under the three different conditions is that the emergence from the cages containing moss as hibernation quarters was much later than the emergence from the other two sets of cages. Spanish moss has been proven to be difficult to warm up sufficiently to force the weevils out of winter quarters before late in the season and the results at Madison, Fla., corroborate this fact in every way.

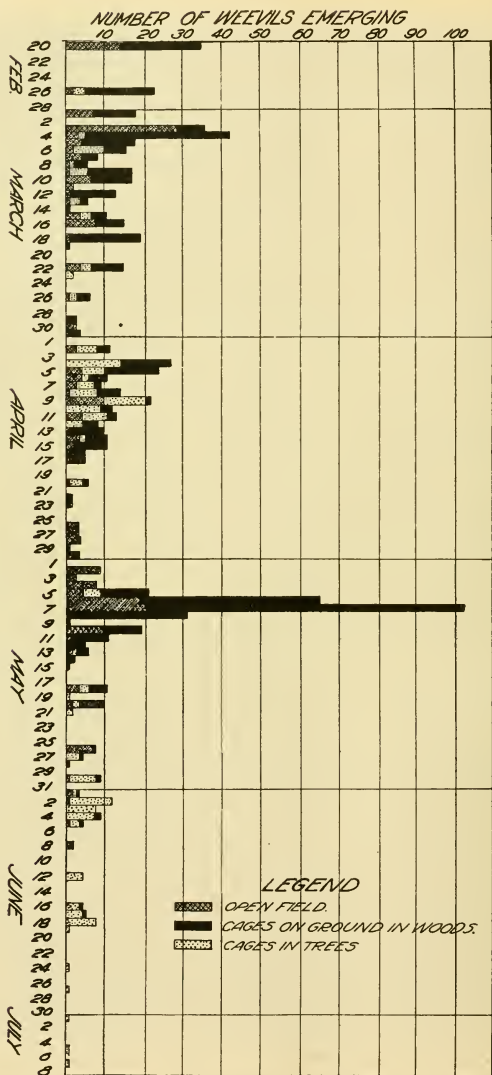


FIG. 16.—Showing the daily rate of emergence of the boll weevil when hibernating in the open field, on the ground in the woods, and in the moss-covered trees, Madison, Fla.

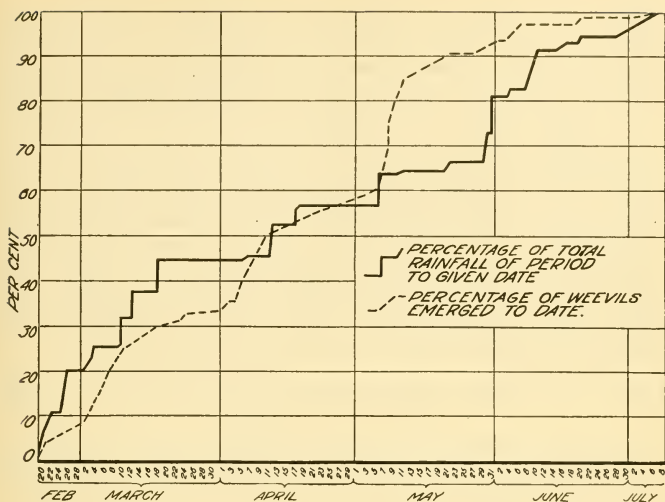


FIG. 17.—Showing the total percentage of rainfall compared with the total percentage of emergence of the boll weevil, Madison, Fla.

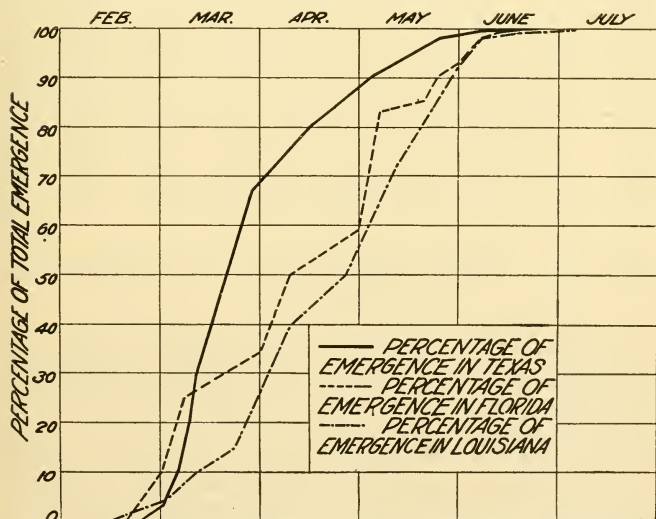


FIG. 18.—Illustrating the rate of emergence from hibernation of the boll weevil in Texas, Louisiana, and Florida.

The rate of emergence in Florida as compared to the rates of emergence in Louisiana and Texas is illustrated in the accompanying diagram (fig. 18). Twenty-five per cent of the boll weevils emerge in Florida a few days before the same percentage emerges in Texas and at least 20 days earlier than in Louisiana. The rate of emergence in Texas shows that 50 per cent of the weevils are out of hibernation approximately 20 days before 50 per cent are out in Florida. After 50 per cent of the weevils emerge the figure shows that the rate of emergence in Florida closely approximates the rate of emergence in Louisiana. This is to be expected since the hibernation shelter in Louisiana and Florida is decidedly more dense than the hibernation shelter found in Texas. Table XVII presents the records showing the percentage of total emergence of the boll weevil at different dates and places where hibernation experiments have been conducted.

TABLE XVII.—*Percentage of total emergence of boll weevils at different dates and at different places.*

Date.	Keatchie, La., 1906.	Tallulah, La.		Mansura, La.		Dallas, Tex.		Calvert, Tex., 1907.	Victoria, Tex., 1907.	Madison, Fla., 1919.
		1910.	1911.	1910.	1909.	1907.	1908.			
Feb. 21.....	0.00	0.31	36.95	1.64	7.20	0.00	0.00	0.00	0.00	3.6
Feb. 28.....	.00	.31	36.95	3.28	10.61	.00	.00	.00	12.01	5.03
Mar. 7.....	.00	6.62	39.92	10.56	19.22	24.48	7.27	22.80	27.92	21.9
Mar. 14.....	.00	10.09	63.83	15.69	19.73	36.36	23.63	31.90	48.23	30.2
Mar. 21.....	.00	13.56	70.35	21.19	23.24	57.14	45.45	44.30	66.24	34.2
Mar. 28.....	3.93	23.34	72.52	38.05	30.96	71.72	55.45	57.20	79.35	36.4
Apr. 4.....	6.87	35.95	74.69	46.53	38.16	75.70	63.63	64.20	84.16	41.4
Apr. 11.....	24.54	41.65	81.21	49.42	43.87	81.28	68.18	70.40	89.58	52.3
Apr. 18.....	32.11	46.05	87.73	52.41	47.78	84.46	74.54	77.40	93.80	57.7
Apr. 25.....	40.67	48.89	96.42	53.86	56.39	85.74	87.27	79.51	95.02	58.4
May 2.....	52.73	61.83	96.42	60.41	61.30	88.62	90.91	82.62	95.88	61.2
May 9.....	60.44	70.66	98.59	72.35	67.51	92.30	91.82	88.73	97.50	85.4
May 16.....	72.22	75.39	98.59	75.64	75.12	95.75	94.55	91.94	98.36	90.4
May 23.....	86.41	88.64	98.59	84.77	82.43	98.76	98.18	94.95	98.92	92.5
May 30.....	91.60	93.69	98.59	92.77	89.73	99.34	98.18	97.56	99.18	94.7
June 6.....	97.36	99.05	100.00	98.43	96.83	99.78	99.09	99.17	99.90	98.5
June 13.....	99.19	99.68	100.00	99.89	97.83	99.88	99.09	99.68	99.97	99.1
June 20.....	99.61	99.68	100.00	100.00	98.74	100.00	100.00	99.99	100.00	99.6
June 27.....	99.89	100.00	100.00	100.00	99.94	100.00	100.00	100.00	100.00	99.9
July 4.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.9
July 7.....	-----	-----	-----	-----	-----	-----	-----	-----	-----	100.00

NUMBER OF BOLL WEEVILS SURVIVING THE WINTER WHEN HIBERNATING IN THE OPEN FIELD.

In Table XVIII are presented the data on the number of weevils surviving the winter when installed in the hibernation cages at different dates in the fall under open field conditions. Of a total of 4,300 weevils installed in the cages an average of 5.76 per cent survived the winter. The cage installed on November 15 showed the greatest percentage of the total emergence, while the cage installed on October 1 gave the smallest percentage of emergence. Emergence from hibernation started in all of the cages, except the one installed on December 1, on February 20. As was to be expected the date of

last emergence was made by a weevil placed in the hibernation cage on December 1. The dates on which 25, 50, and 75 per cent of the weevils had emerged follow very closely the sequence of installation.

TABLE XVIII.—*Hibernation of the boll weevil in open field cages, winter 1918-19.*

Cage No.	Date started.	Number of weevils installed.	Date of first emergence.	Date of last emergence.	Date on which 25 per cent had emerged.	Date on which 50 per cent had emerged.	Date on which 75 per cent had emerged.	Period of emergence	Number emerging.			Percentage of survival.
									Males	Females	Total.	
	1918.		1919.	1919.	1919.	1919.	1919.	Days.				
1.....	Oct. 1	1,000	Feb. 20	Mar. 16	Feb. 20	Feb. 20	Mar. 16	24	1	1	2	0.2
4.....	Oct. 15	1,000	do	May 27	Mar. 1	Mar. 8	Apr. 2	96	17	21	38	3.8
7.....	Nov. 1	1,000	do	June 2	Mar. 7	Apr. 2	May 6	102	23	22	45	4.5
10.....	Nov. 15	1,000	do	June 1	Mar. 16	Apr. 17	do	101	68	59	127	12.7
13.....	Dec. 1	300	Mar. 10	June 5	Apr. 11	May 4	May 10	87	14	9	23	7.6
Total.		4,300	Feb. 20					410	123	112	235	
Av.		860						82	24.6	22.4	47	5.76
Max.		1,000						102	68	59	127	12.7
Min.		300						24	1	1	2	.2

NUMBER OF BOLL WEEVILS SURVIVING THE WINTER WHEN HIBERNATING ON THE GROUND IN THE WOODS.

Woods shelter has always been considered one of the ideal places for successful hibernation of the boll weevil. The results secured at Madison showed a total percentage of survival of 12.8 as compared to 5.76 per cent for the open field. The results of the woods hibernating experiments are presented in Table XIX. In every case the emergence started from the cages on February 20. The cage installed October 1 gave the smallest percentage of emergence (0.8), while the cage installed November 15 gave the highest emergence (20.7 per cent).

TABLE XIX.—*Hibernation records of adult boll weevils in cages on ground in woods.*

Cage No.	Date started.	Number of weevils installed.	Date of first emergence.	Date of last emergence.	Date on which 25 per cent had emerged.	Date on which 50 per cent had emerged.	Date on which 75 per cent had emerged.	Period of emergence	Number emerging.			Percentage of survival.
									Males	Females	Total.	
	1918.		1919.	1919.	1919.	1919.	1919.	Days.				
2.....	Oct. 1	1,000	Feb. 20	Apr. 2	Feb. 20	Feb. 26	Mar. 4	41	4	4	8	0.8
5.....	Oct. 15	1,000	do	June 17	Mar. 4	Mar. 16	Apr. 5	117	19	22	41	4.1
8.....	Nov. 1	1,000	do	June 1	Apr. 4	May 6	May 7	101	115	81	196	19.6
11.....	Nov. 15	1,000	do	June 8	Mar. 5	Apr. 2	Apr. 28	108	113	94	207	20.7
14.....	Dec. 1	300	do	June 16	Mar. 12	May 7	May 7	116	30	27	57	19.0
Total.		4,300						483	281	228	509	
Av.		860						96.6	56.2	45.6	101.8	12.8
Max.		1,000						117	115	94	207	20.7
Min.		300						41	4	4	8	0.8

NUMBER OF BOLL WEEVILS SURVIVING THE WINTER WHEN HIBERNATING IN SPANISH MOSS 10 FEET ABOVE GROUND.

The data on the survival of the weevils in cages installed 10 feet above ground in trees are presented in Table XX. Only 4.54 per cent of the 4,400 weevils installed in the cages in the trees survived the winter. The cage installed on November 15, however, gave a total emergence of 10.2 per cent. In connection with the dates of the beginning of emergence of the hibernated weevils it is interesting to note the manner in which the moss held back the weevils, the first emergence not occurring before February 26, and the last emergence taking place on July 7.

TABLE XX.—*Hibernation record of boll weevils in cages installed in the trees.*

Cage No.	Date installed.	Number of weevils in cage.	Date of first emergence.	Date of last emergence.	Date on which 25 per cent had emerged.	Date on which 50 per cent had emerged.	Date on which 75 per cent had emerged.	Period of emergence.	Number emerged.			Height above ground.	Per cent of survival.
									Males.	Females.	Total.		
	1918.		1919.	1919.	1919.	1919.	1919.	Days					
3.....	Oct. 1	1,000						0	0	0	0	10	0
6.....	Oct. 15	1,000	Mar. 3	July 1	Apr. 2	Apr. 9	Apr. 14	106	33	27	60	10	6.0
9.....	Nov. 1	1,000	Mar. 6	July 7	May 10	June 2	June 4	113	20	18	38	10	3.8
12.....	Nov. 15	1,000	Mar. 4	July 5	Apr. 7	May 5	June 2	112	60	42	102	10	10.2
15.....	Dec. 1	400	Feb. 26	May 20	Feb. 26	Mar. 8	May 4	83	6	5	11	10	2.7
Total.....		4,400						414	119	92	211	50	
Av.....		880						82.8	23.8	18.4	42.2	10	4.54
Max.....		1,000						113	60	42	102	10	10.2
Min.....		400						83	0	0	0	10	0

SUMMARY OF THE HIBERNATION OF THE BOLL WEEVIL UNDER ALL CONDITIONS, WINTER 1918-19.

Table XXI gives a summary of the hibernation records secured at Madison, Fla., during the winter 1918-19. The records show that of 13,100 weevils installed in the three sets of hibernation cages at different dates during the fall of 1918, only an average of 7.54 per cent survived the winter. The highest percentage of survival is shown in the cages installed in the woods on the ground. The second highest percentage of survival was in cages installed in the open field and the lowest percentage of survival in the cages installed 10 feet above the ground. It is also noticeable that in every case weevils placed in the hibernation cages on November 15 survived in greater numbers than those placed in the cages at an earlier or later date. It is evident that weevils that become adult right at the time of entrance into hibernation are not in as good physical condition to go through the winter as weevils that have had time to feed longer and thus get their stomach contents in proper condition for entering hibernation. The maximum survival by the weevils that were placed

in the hibernation cages on November 15 was followed in order of total emergence by the survival of weevils placed in the cages November 1 and December 1, respectively.

TABLE XXI.—*Summary of hibernation of Anthonomus grandis under all conditions—winter 1918-19.*

Date started.	Total number of weevils placed in cages.	Open field.		On ground in woods.			In trees in woods.			Total number weevils emerged.		Total percentage surviving winter.	
		Number emerged.		Per cent age surviving winter.	Number emerged.		Per cent age surviving winter.	Number emerged.		Per cent age surviving winter.			
		Males.	Fe-males.		Males.	Fe-males.		Males.	Fe-males.		Males.		Fe-males.
1918.													
Oct. 1. . .	3,000	1	1	0.2	4	4	0.8	0	0	0	5	5	0.3
Oct. 16. . .	3,000	17	21	3.8	19	22	4.1	33	27	60	69	70	4.6
Nov. 1. . .	3,000	23	22	4.5	115	81	19.6	20	18	3.8	158	121	9.3
Nov. 15. . .	3,000	68	59	12.7	113	94	20.7	60	42	10.2	241	195	14.5
Dec. 1. . .	1,100	14	9	7.6	30	27	19.0	6	5	2.7	50	41	9.0
Total..	13,100	123	112	.....	281	228	.....	119	92	.....	523	432	.....
Av.....		24.6	22.4	5.76	56.2	45.6	12.8	23.8	18.4	15.34	104.6	86.4	7.54
Max.....		68	59	12.7	115	94	20.7	60	42	60	241	195	14.5
Min.....		1	1	0.2	4	4	0.8	6	5	0	5	5	0.3

GENERAL SUMMARY.

At Madison, Fla., the average longevity of hibernated weevils without food was 12.7 days, and 18.8 days when fed on cotton plantlets. Adult weevils of the first and second generations lived 24.3 days on cotton squares and 12.3 days on cotton bolls.

On sea-island cotton plantlets the hibernated weevils lived 11.05 days. The first and second generation weevils fed on sea-island cotton squares lived 10.7 days, while the weevils fed on sea-island cotton bolls lived only 15.3 days.

There is practically no difference in the longevity of boll weevils on sea-island and upland cottons.

The average period from the time the weevils become adult to oviposition at Madison, Fla., for all experiments, was 8.9 days for weevils bred under insectary conditions and 7.07 days for weevils bred under field conditions.

The average period of oviposition under insectary conditions for all weevils under observation on upland cotton was 33.1 days. The entire series deposited eggs over an average period of 31.7 days on sea-island cotton. The largest number of eggs deposited by a single female weevil was 432. This record was made by a hibernated female on upland cotton squares under insectary conditions. The largest number of eggs deposited during any one day under insectary conditions was 25. This record was also made by a hibernated female weevil.

The average period from oviposition to adult of all weevils bred under insectary conditions on upland cotton squares was 14.91 days. On sea-island cotton the average period from egg to adult for all weevils bred under insectary conditions was 14.94 days.

The field-bred weevils showed more vitality than weevils bred under artificial conditions.

Under field conditions the average length of time the infested squares hung on the upland cotton plants after egg puncture was 11.5 days. The time required to complete the development of the immature weevil after the infested square dropped to the ground was 10.8 days in upland cotton squares.

There was practically no difference shown in the length of the developmental period of the boll weevils bred in short-staple upland, long-staple upland, and sea-island cotton squares.

The developmental period of the boll weevil was approximately 7.5 days longer under field conditions than under insectary conditions at Madison, Fla.

Soil temperatures of 120° F. and higher are usually fatal to the immature weevils under field conditions.

The boll weevil at Madison, Fla., shows a decided tendency to form a new variety.

The hibernation of the weevil at Madison, Fla., is incomplete and the adults are seldom inactive more than 30 days at a time.

The emergence from hibernation of the weevil in Florida is very gradual, the total daily emergence bearing a direct relation to the total daily rainfall.

Weevils survived the winter in larger numbers in cages set on the ground in the woods than in the open field or in cages in trees 10 feet above ground. Weevils placed in hibernation cages on November 15 survived in larger numbers than on any other date of installation.

The percentage of total emergence from hibernation begins with more acceleration in Florida than in Texas up to the time that 25 per cent emerges. After 25 per cent of the weevils have emerged in Florida the emergence is less rapid and the Florida emergence curve very closely approaches the emergence curve for Louisiana.

The total percentage of hibernating weevils that survived the winter of 1918-19 at Madison, Fla., was 7.54.

UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 932

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.

PROFESSIONAL PAPER

September 20, 1921

LIFE HISTORY OF THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO

By

E. H. SIEGLER, Entomologist, and H. K. PLANK, Scientific
Assistant, Fruit Insect Investigations, in Coopera-
tion with The Colorado Agricultural
Experiment Station

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INTRODUCTION.

The codling moth, *Laspeyresia pomonella* (L.) (Pl. I, A) is generally recognized as the most serious insect pest attacking the fruit of the apple and pear and is particularly abundant and destructive in the Grand Valley of Colorado. As a result of the extensive injury to the fruit industry of this valley for which this insect is responsible, it was deemed desirable to make a thorough study of its life history as a basis for control experiments.

The data reported in the present publication fill an urgent need of long standing for more complete and useful information regarding the seasonal habits of the codling moth in the Grand Valley of Colorado. It should form a basis for constructive control measures for the use of orchardists in this region.

The plans for this investigation were made by the United States Department of Agriculture, Bureau of Entomology, in cooperation with the Colorado Agricultural Experiment Station. The work was done under the general supervision of Dr. A. L. Quaintance, in charge of deciduous fruit insect investigations, Bureau of Entomology, and Prof. C. P. Gillette, director and entomologist of the Colorado Agricultural Experiment Station.

A field station was established at Grand Junction, Colo., in the fall of 1914, by Mr. R. J. Fiske, of the Bureau of Entomology. The senior author was placed in immediate charge of the work in 1915, and was assisted during the year by Mr. E. R. Van Leeuwen, of the Bureau of Entomology, and in 1916 by the junior author. Much valuable information was given from time to time by Messrs. George M. List and Claude Wakeland, of the entomological department of the Colorado Agricultural Experiment Station.

The general character of the work in the Grand Valley was quite similar to that of the codling-moth investigations conducted by the Bureau of Entomology in several other fruit districts, but it was carried out on a somewhat larger scale and includes certain phases of the life history and habits of the codling moth not hitherto reported.

THE GRAND VALLEY OF COLORADO.

LOCATION AND DESCRIPTION.

The Grand Valley of Colorado is located in Mesa County, on the western slope of the Rocky Mountains, is about 32 miles in length, and has an extreme width of 5 miles. It comprises nearly 75,000 acres of land, about one-fifth of which is planted to fruit. At the time of these investigations there were approximately 10,000 acres of apples and about 2,500 acres of pears, while the remainder of the fruited area was devoted chiefly to peaches, plums, cherries, apricots, and bush fruits. The great majority of the orchards, of which the one shown in Plate II is a good example, were planted north of the Grand River, which flows through the entire length of the valley.

TOPOGRAPHY AND ELEVATION.

The valley is comparatively level, with the exception of a few elevations known locally as the "Fruit Ridges." The fruit district of Orchard Mesa, while higher than most other parts of the valley, is typical tableland. The general elevation of the Grand Valley

varies from about 4,500 to 4,800 feet, Grand Junction being approximately 4,600 feet above sea level.

CLIMATE.

The climate is relatively dry, the annual rainfall being usually 8 to 9 inches, distributed according to the normal precipitation up to and including 1916 as follows: January 0.49, February 0.64, March 0.71, April 0.76, May 0.92, June 0.40, July 0.50, August 1.04, September 0.95, October 0.91, November 0.55, December 0.44, or a total of 8.31 inches per year. Moisture is supplied the crops by means of irrigation systems, use being made of the water from the Grand River.

The day temperatures during the summer season are high, while those at night are relatively low. For further details as to weather conditions in the Grand Valley see Tables I and II (pp. 4 and 5), which give the annual meteorological summaries of the United States Weather Bureau for the years 1915 and 1916.

EXPLANATION OF TERMS.

In conformity with the previous life-history studies of the codling moth by members of the Bureau of Entomology, certain definitions of the terms employed have been adopted.

The term "generation" is here used to include all the consecutive stages of the codling moth throughout the season, starting with the egg and ending with the adult or moth. Thus the first eggs to be laid (those deposited by the first moths of the season) would start the first generation; these and the resulting larvæ, pupæ, and moths would belong to this generation. The eggs deposited by the moths which belong to the first generation start the second generation, to which also belong the resulting larvæ, pupæ, and moths, and so on.

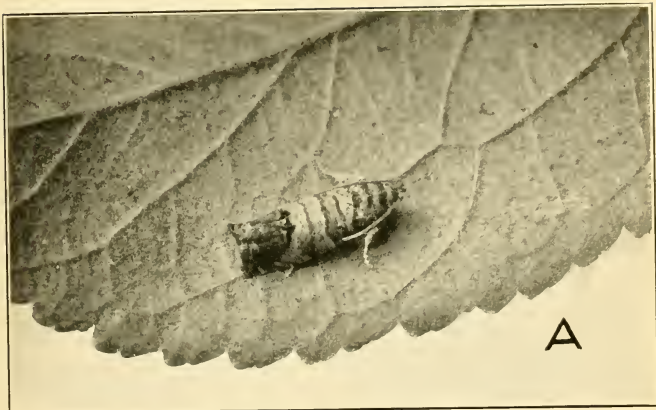
The term "brood" as used in this publication is applied to any stage of the codling moth which may belong to a specific generation or to an unknown generation. For example, the eggs, larvæ, pupæ, and moths which belong to the first generation are called first-brood eggs, larvæ, etc.

The larvæ which pass the winter include all the nontransforming larvæ of the first and second broods, and, in the Grand Valley of Colorado, all of the larvæ of the third brood. The specific generation to which each of these individuals belongs can not be determined unless they have been reared. The term "generation," therefore, can not properly be used to include the various stages of their transformations; they are simply called "wintering" or "spring-brood" larvæ, and the pupæ and moths into which they transform are designated "spring-brood" pupæ and moths.

TABLE I.—*Annual meteorological summary, Grand Junction, Colo., 1915.*

Month.	Temperature (° F.).				Precipitation (inches).		Relative humidity.		Sun-shine.		Wind.			Number of days.																		
	Extremes.				Precipitation (inches).		Relative humidity.		Sun-shine.		Wind.			Number of days.																		
	Means.		Date.		Precipitation (inches).		Relative humidity.		Sun-shine.		Wind.			Number of days.																		
	Maximum.	Minimum.	Monthly.	Highest.	Date.	Lowest.	Date.	Total.	Greatest in 24 hours.	Total snowfall.	Mean at 6 a. m.	Mean at 6 p. m.	Lowest observed.	Number of hours.	Per cent of possible.	Average velocity (miles per hour).	Prevailing direction.	Maximum velocity (for 5 minutes).	Winds of 40 miles or more per hour.	Clear.	Partly cloudy.	Cloudy.	Precipitation (0.01 inch or more).	Thunderstorms.	Dense fog.	Snowfall (0.01 inch or more melted).	Max. temp. 32° or below.	90° or above.	Min. temp. 32° or below.	0° or below.		
January.....	31	9	20	41	3	4	24	0.77	0.28	7.1	93	68	25	193	64	5.5	4.4	W.	21	0	11	8	12	7	0	3	6	19	0	31	4	
February.....	43	2	35	58	11	15	8	0.53	0.29	1.1	86	60	37	166	55	5.5	5.8	W.	39	0	10	7	11	8	0	5	0	0	24	0	0	
March.....	55	32	43	67	26	26	1	0.10	0.10	0.1	83	28	11	256	69	5.1	6.6	W.	48	1	10	14	7	2	0	0	1	0	20	0	0	
April.....	68	45	56	79	28	34	1	1.41	0.47	0	66	34	13	222	56	5.4	8.0	SE.	42	1	8	15	7	11	9	0	0	0	0	0	0	
May.....	70	46	58	88	13	29	2	1.23	0.62	T.	58	30	10	264	60	5.6	8.0	SE.	47	1	9	12	10	6	0	0	0	0	0	0	0	
June.....	82	54	68	93	24	43	4	0.92	0.43	0	46	20	5	377	84	3.0	7.8	E.	45	1	19	7	4	6	5	0	0	0	0	0	0	
July.....	91	64	77	97	11	56	4	0.16	0.13	0	42	20	9	372	82	3.2	8.0	E.	36	0	16	4	4	3	9	0	0	0	18	0	0	
August.....	89	61	73	95	4	54	17	0.51	0.25	0	47	24	8	340	80	2.9	7.9	E.	33	0	19	10	2	7	10	0	0	0	15	0	0	
September.....	78	53	66	90	1	42	14	0.85	0.81	0	56	29	12	275	74	3.8	7.8	SE.	45	1	15	12	3	5	5	0	0	0	1	0	0	
October.....	69	40	54	79	2	33	31	0.91	0.01	0	50	24	12	313	90	2.0	5.9	SE.	29	0	24	5	2	1	0	0	0	0	0	0	0	
November.....	50	28	39	71	5	11	28	0.71	0.27	4.5	66	50	8	230	76	4.9	6.3	E.	43	1	14	6	15	3	0	5	0	0	0	20	0	
December.....	39	22	30	55	14	10	28	1.15	0.38	13.8	85	68	24	104	56	6.3	5.0	SE.	22	0	7	9	15	9	0	8	0	9	0	29	0	
Year.....	64	40	52	97	July 11.	Jan. 24.	8.45	0.81	28.6	70	63	38	5	3,172	70	4.4	6.8	SE.	48	6	162	119	84	77	45	3	25	28	43	126	4	4

NOTE.—Precipitation includes rain and melted snow, hail, and sleet. "T." indicates trace of precipitation.



A. ADULT MOTH RESTING ON APPLE LEAF.



B. PAIR OF MOTHS IN COPULA.

THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.



THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

View of experimental orchard.

TABLE II.—*Annual meteorological summary, Grand Junction, Colo., 1916.*

Month.	Temperature (° F.).				Precipitation (inches).			Relative humidity.			Sun-shine.		Wind.				Number of days.														
	Means.		Extremes.		Total.	Greatest in 24 hours.	Total snowfall.	Mean at 6 a. m.	Mean at 6 p. m.	Lowest observed.	Number of hours.	Per cent of possible.	Average cloudiness (scale of 0 to 10).	Average velocity (miles per hour).	Prevailing direction.	Maximum velocity (for 5 minutes).	Winds of 40 miles or more per hour.	Clear.	Partly cloudy.	Cloudy.	Precipitation (0.01 inch or more).	Thunderstorms.	Dense fog.	Snowfall (0.01 inch or more melted).	Max. temp.		Min. temp.				
																									90° or above.	32° or below.					
		Maximum.	Minimum.	Monthly.	Highest.	Date.	Lowest.	Date.																		32° or below.	90° or above.	32° or below.	0° or below.		
January.....	32	13	22	50	28	7	31	1.18	0.23	15.2	92	78	36	130	43	7.5	5.2	NW.	51	1	4	8	19	16	1	15	16	0	31	2	
February.....	43	21	32	54	24	19	1	0.45	0.16	1.5	89	68	36	228	73	4.6	4.6	NW.	36	0	10	12	7	6	0	3	4	0	28	2	
March.....	58	34	46	72	19	16	3	0.71	0.32	6.9	63	36	12	301	81	3.9	7.6	NW.	34	0	17	6	8	7	0	2	1	0	12	0	
April.....	66	40	53	82	28	27	20	0.20	0.13	0.9	58	27	8	283	71	3.4	7.4	SE.	37	0	9	13	8	4	0	1	0	0	7	0	
May.....	73	45	59	88	9	32	15	1.05	1.04	0	43	15	5	359	81	3.8	8.9	NW.	47	1	16	10	5	3	1	0	0	0	0	0	
June.....	86	57	72	94	30	43	2	T.	T.	0	30	10	5	418	94	1.7	8.4	NW.	34	0	25	5	0	0	1	0	0	0	0	0	
July.....	90	64	77	98	1	57	4	0.76	0.33	0	52	28	8	333	73	4.3	8.0	SE.	37	0	9	17	5	8	11	0	0	0	0	0	
August.....	84	61	72	92	4	54	31	2.16	0.75	0	62	32	10	319	75	4.6	7.6	SE.	35	0	14	13	4	8	12	0	0	1	0	0	
September.....	79	52	66	88	6	42	28	0.50	0.28	0	54	24	12	318	85	2.6	7.7	SE.	37	0	19	10	1	4	3	0	0	0	0	0	
October.....	63	39	51	75	6	29	19	2.12	0.52	0	78	46	23	247	71	3.4	7.1	SE.	38	0	18	7	6	11	4	0	0	0	8	0	
November.....	48	23	36	69	5	6	13	0.34	0.19	4.8	72	42	22	254	84	5.6	5.9	SE.	36	1	19	3	2	0	0	2	2	0	26	0	
December.....	35	14	25	55	6	28	0	0.27	0.14	5.8	84	63	32	181	62	5.4	5.8	NW.	38	0	9	14	8	0	7	15	0	30	1		
Year.....	63	39	51	98	July 5.	—9	Feb. 1.	9.74	1.04	35.1	65	39	5	3,370	74	4.1	7.0	SE.	56	3	169	123	74	77	32	4	30	38	28	142	5

NOTE.—Precipitation includes rain and melted snow, hail, and sleet. "T." indicates trace of precipitation.

As mentioned previously and explained later, the larvæ which hatch from the eggs deposited by the second brood of moths do not transform into pupæ and moths the same season as hatched, but pass the winter in the larva stage. Hence there is, in the Grand Valley of Colorado, what might be called a "partial" or "incomplete" third generation. However, these eggs and larvæ are known as third-brood eggs and larvæ.

The "life cycle" of a generation includes the time from the deposition of the egg to the emergence of the moth of the same generation.

The "complete life cycle" extends from the time of the deposition of the egg of one generation to the deposition of the egg of the next generation and, strictly speaking, should include the female sex only.

The seasonal-history studies begin with the wintering or spring-brood larvæ which transform to pupæ of the spring brood and from which issue the moths of the spring brood.

The moths of the spring brood deposit the eggs of the first brood, which, upon hatching, are known as larvæ of the first brood. Some of these remain in the larva stage until the following spring, while the remainder transform successively into the pupæ and moths of the first brood.

The moths of the first brood produce the eggs of the second brood, which, after their incubation period, result in the larvæ of the second brood. Some of these, like some of the first-brood larvæ, are wintering individuals, while the others transform and become successively the pupæ and moths of the second brood.

The moths of the second brood deposit the eggs of the third brood. In the Grand Valley of Colorado all the larvæ of this brood pass the winter, comprising part of the spring brood of pupæ and moths the following season.

Wintering larvæ or larvæ of the spring brood (spring-brood larvæ) include: All of the nontransforming larvæ of the first and second broods and all of the larvæ of the third brood.

Pupæ of the spring brood (spring brood pupæ) include: All of the pupæ from the spring-brood larvæ.

Moths of the spring brood (spring-brood moths) include: All of the moths from the pupæ of the spring brood.

The first generation includes:

1. The eggs of the first brood.
2. The larvæ of the first brood:
 - (a) Transforming first-brood larvæ;
 - (b) Wintering first-brood larvæ.
3. The pupæ of the first brood.
4. The moths of the first brood.

The second generation includes:

1. The eggs of the second brood.
2. The larvæ of the second brood:
 - (a) Transforming second-brood larvæ;
 - (b) Wintering second-brood larvæ.
3. The pupæ of the second brood.
4. The moths of the second brood.

The third generation (not complete in the Grand Valley) includes:

1. The eggs of the third brood.
2. The larvæ of the third brood, all of which are wintering individuals.

METHODS AND REARING APPARATUS EMPLOYED IN THE LIFE-HISTORY STUDIES.

The methods used in the study of the biology of the codling moth in the Grand Valley were in most respects like those employed in similar investigations of the bureau at other places.

The rearing apparatus likewise conformed with that previously used, with the exception of an improved cocooning rack, devised by Mr. Van Leeuwen. This device was made of wooden strips 8 inches long, $1\frac{3}{4}$ inches wide, $\frac{1}{4}$ inch thick, having two rows of compartments or cells, each cell of which would accommodate one codling moth larva. These cells were covered with a strip of celluloid, through which the transformation of the insect could be observed, and the record of the observations was kept by placing a reference number at the head of each cell in the space provided for that purpose. After the inspection of the insects, the cells were covered by a strip of wood one-eighth inch in thickness, which was held in place by means of wire clamps made from paper clips. Three views of the cocooning rack are shown in Plate III: *a*, the rack with cover removed, showing the cells and larvæ within as well as the reference numbers; *b*, side view, showing cover held in place by wire clamps; *c*, top view.

The cages used in the studies usually consisted of glass battery jars, 6 by 8 inches, covered with cloth tops which are held in place by rubber bands.

The oviposition cages consisted of the regular battery jars, the bottoms of which were covered with a 2-inch layer of slightly moist sand. A fresh twig of apple or pear foliage was placed daily in each cage, as was also a small piece of sponge moistened with a solution of brown sugar.

The incubation cages, in which the eggs were kept, were similar to those used for oviposition purposes. The leaves, on which the eggs had been deposited, were held in a flat position between two pieces of wire screen for a day or more to prevent curling while they dried.

Pupation studies.—The time of pupation of the larvæ was found by a daily examination of the cocooning racks.

Studies of the pupal period.—The pupal period was determined for each individual by noting the time of pupation and emergence of the moth.

Studies of moth emergence.—The records of the emergence of moths were made daily.

Studies of the oviposition.—In order to secure data on the oviposition of the moths, it was necessary to confine the moths issuing on different days in separate cages. The foliage in these cages was removed daily and the number of eggs recorded.

Studies of the length of life of moths.—At the time of changing the foliage in the oviposition cages, all dead moths were removed. The sex was then determined and the length of life computed.

Studies of the incubation period.—The two distinct embryological stages of the eggs previous to hatching were noted, namely, (1) the "red-ring stage," or the first marked indication of the development of the circulatory system, and (2) the so-called "black-spot stage," or the initial appearance of the black head of the developing larva. (See Pl. IV, B.)

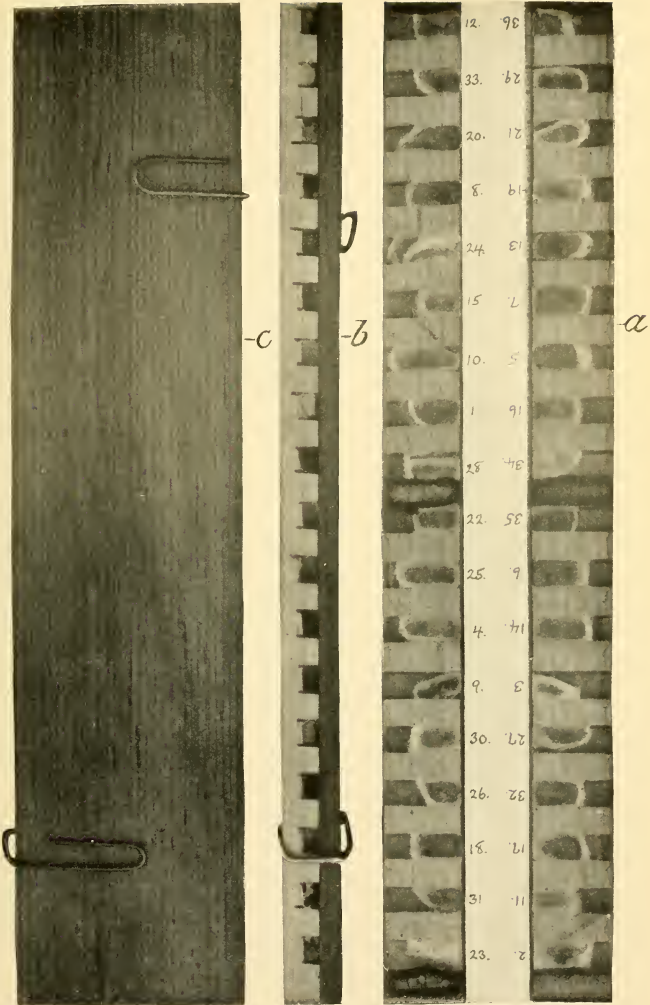
Studies of the larval feeding periods.—The feeding studies of the larvæ of the first brood were conducted in two ways: (1) By the stock-jar method and (2) by the bagged-fruit method. The feeding periods of the larvæ of the second and third broods were ascertained according to the stock-jar method only.

In the stock-jar method, apples free from codling-moth larvæ were placed in a wire basket within a battery jar into which were introduced newly-hatched larvæ. These soon entered the apples and completed their feeding period within the fruit. Cocooning racks were placed in each jar and these were examined daily to ascertain when the larvæ left the fruit, and from these data the length of the feeding period was computed.

The bagged-fruit method consisted in placing newly-hatched larvæ on apples developing on the tree and covering the fruit with finely perforated paper bags. The fruit selected was first carefully examined to insure its freedom from previous infestation. The inclosed fruit was allowed to remain on the tree for a period of two weeks, after which it was removed and kept at the insectary under conditions identical with those described for the stock-jar method.

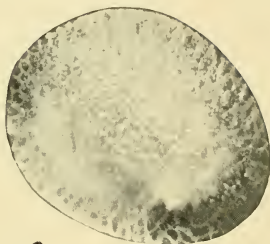
THE INSECTARY.

Most of the life-history studies of the codling moth were made at the insectary, a partial interior view of which is shown in Plate V. This was located to the rear of the laboratory and was partially



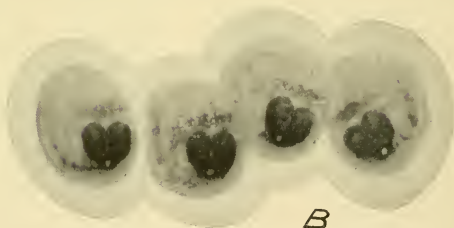
THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

Three views of cocooning rack: *a*, With cover removed to show the cocooning cells;
b, side view; *c*, top view.



A

A. Egg.
Greatly enlarged.

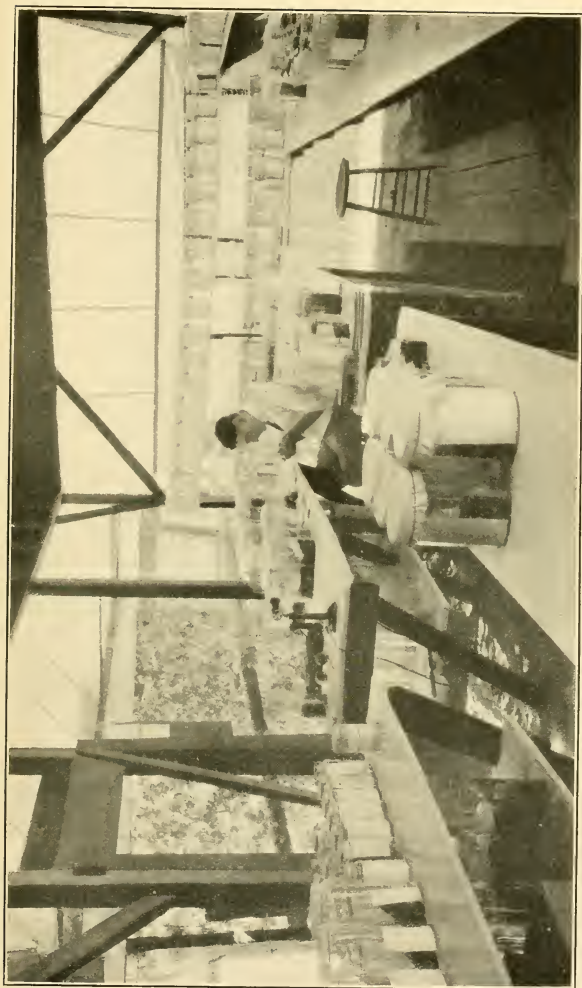


B

B. EGGS IN ADVANCED BLACK-SPOT STAGE ALMOST
READY TO HATCH.

Greatly enlarged.

THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

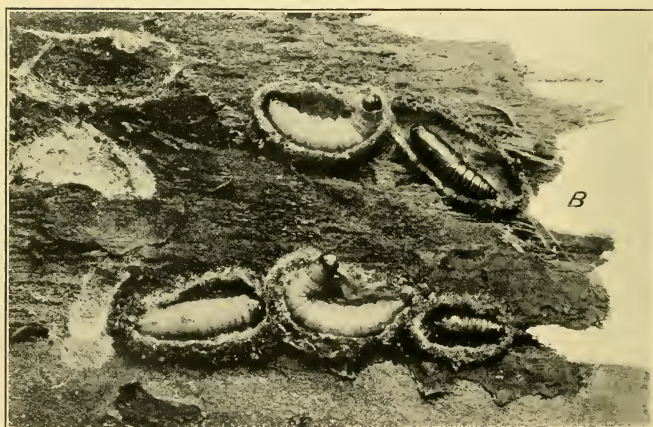


THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

Interior view of insectary.



A. APPLES INFESTED WITH LARVÆ.



B. LARVÆ AND PUPÆ IN COCOONS.

THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

shaded by trees, vines, awnings, and other buildings. As will be noted in the photograph, the insectary was of open-type construction, permitting free circulation of the air; it was 40 feet long and 11 feet wide, with the lowest part of the roof 11 feet in elevation. The temperature conditions within the insectary closely paralleled those in the orchards, as was determined by frequent observations. A thermograph and maximum and minimum thermometers were kept in the insectary for temperature records; and the average daily temperatures used in the various graphs and charts throughout this publication were computed for each day by adding the temperature recorded by this thermograph for each hour of that day and dividing the sum by 24. Other data pertaining to weather conditions were obtained through the courtesy of the local station of the United States Weather Bureau, which was located within a half mile of the insectary.

SEASONAL-HISTORY STUDIES OF 1915.

The seasonal-history studies of the codling moth were commenced in 1915 with the observations of the time of pupation of the spring-brood larvæ.¹ The climate throughout the season was generally normal, except in early May, when subnormal temperatures which fell below the freezing point occurred successively on the mornings of May 1 to 4 inclusive and again on May 7. On the 2d of May the temperature dropped to 22° or 23° F. in many sections of the valley, one exception being the Palisade peach district, which is usually favored with higher minimum temperatures. At the time of the freezes most apples had just dropped their blossoms, except the late-blooming varieties, as Rome Beauty and Jeniton.

As a result of the low temperatures, the apple crop in the Grand Valley, with the exception of that included in the Palisade district and in a few orchards where oil heaters were employed, was practically destroyed. Here and there were to be found a few pears, the blossoms of which seemingly were not so readily destroyed by the freezes as were those of the apple. The general shortage of the apple crop, however, did not in any way interfere with the life-history studies, since sufficient fruit was at hand for feeding and other purposes.

In referring to the tables the reader should bear in mind that each table is a unit in itself. Successive tables are not necessarily continuations of the life history of all of the individuals given in the previous table. For example, it will be noted that Table III is the record of the time of pupation of 320 wintering larvæ and that Table IV includes observations on the length of the pupal stage of only 233 of these individuals. Differences of this character may be due to

¹ These larvæ were collected from banded apple trees in the fall of 1914 by Mr. R. J. Fiske, of the Bureau of Entomology.

natural or artificial causes, such as death, accidental injury, parasites, the removal of specimens for other purposes, etc.

WINTERING LARVÆ.

As previously stated (p. 6), the wintering larvæ consist of all of the nontransforming larvæ of the first and second broods and all of the larvæ of the third brood. (See Plate VI, B.)

The winter cocoon.—The winter cocoon is a small, well-built structure, having heavy silk walls in which are frequently interwoven small particles of bark. When compared with the more hastily constructed summer cocoon, it will be noted that the winter cocoon is of heavier construction and thus affords the larva protection against the low temperatures of the winter season. The cocoon is generally more or less oval in form, but varies to conform with the space in which it is built. The winter cocoon is usually found beneath the bark on the trunk of the tree, well concealed from birds and insect enemies, in the crotches of the larger limbs, or in decayed or partially decayed tree cavities, etc. Not infrequently, in the Grand Valley, a mass of 10 to 20 cocoons, side by side or partially on top of one another, may be found on the tree in places particularly favorable for hibernation. The cocoons are occasionally to be found around the base of the tree just below the surface soil or within cracks in the soil. Again, a considerable number of winter cocoons are constructed in various cracks and crevices within packing houses and storage cellars where the harvested fruit has been kept.

Remodeling of the cocoon.—The wintering larva begins activity during the first warm days of spring; it then remodels its cocoon by attaching thereto a slender silken exit tube which provides for the safe issuance of the moth. This tube is usually a fraction of an inch in length, although tubes have been found that were 2 or more inches long, depending upon the location of the cocoon. Upon the completion of the exit tube a lightly constructed silken partition, which serves to separate the tube from the cocoon proper, is frequently built at its base.

Emergence of the moth.—Shortly before the time the moth emerges, the pupa punctures this silken partition and, by means of its retrose spines, wriggles its way to the end of the exit tube. The moth then ruptures the pupal skin, crawls into clear space, spreads and dries its wings, and in due course of time takes flight. Were it not for the exit tube, many moths would be unable to free themselves from the place in which the larvæ have cocooned.

PUPÆ OF THE SPRING BROOD.

Time of pupation.—Observations of the time of pupation of the wintering larvæ were made daily by examination of the larvæ within the cocooning racks. The tabulated results showing the time of

pupation of 320 larvæ are given in Table III and illustrated in figure 1.

It will be noted that the earliest pupation occurred April 14, when two larvæ transformed, and that the last of the wintering larvæ pupated June 8 or approximately 8 weeks later. On April 26 there was a marked increase in the rate of pupation and a still greater increase two days later, owing to higher temperatures, as shown in figure 1. Following this activity the temperatures became abnormally low, reaching in the insectary a minimum of 27° F. on May 2, on this date only one larva pupating. This freeze contributed largely to the destruction of practically the entire fruit crop of the Grand Valley west of the Palisade district. Freezing temperatures recurred on the mornings of May 3, 4, and 7, but on the latter date the temperature reached a maximum of 70° F., and, as a result, 18 larvæ pupated. Pupation thereafter continued quite regularly (except on May 10) and reached its maximum on May 12. During the period of one week, May 7 to 13, inclusive, approximately 40 per cent of the wintering larvæ pupated. Following this crest of activity the rate of pupation gradually diminished in the normal way.

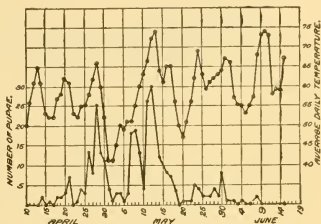


FIG. 1.—Time of pupation of spring-brood pupæ of the codling moth, Grand Junction, Colo., 1915.

TABLE III.—Time of pupation of wintering larvæ of the codling moth, Grand Junction, Colo., 1915.

Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.
Apr. 14	2	Apr. 26	13	May 8	19	May 20	1	June 1	1
15	0	27	8	9	13	21	1	2	1
16	1	28	25	10	4	22	1	3	0
17	0	29	13	11	26	23	5	4	1
18	2	30	11	12	30	24	4	5	0
19	2	May 1	4	13	20	25	2	6	0
20	3	2	1	14	12	26	2	7	1
21	7	3	3	15	10	27	2	8	2
22	0	4	3	16	8	28	4		
23	1	5	1	17	7	29	2		
24	4	6	3	18	4	30	8		
25	3	7	18	19	0	31	1		
								Total...	320

Length of the pupal stage.—In Table IV will be found the length of the pupal stage of 233 pupæ of the spring brood. Reference to this table will show that the first pupation occurred April 14 and the last June 7. The pupal period of the individuals that pupated early in the season was naturally longer, owing to the lower average

temperatures, than was the pupal period of those insects that transformed later in the spring. The average length of the pupal stage was 27.58 days, the maximum 34 days, and the minimum 15 days.

TABLE IV.—*Length of the pupal stage of pupæ of the spring brood of the codling moth, Grand Junction, Colo., 1915.*

Date of pupation.	Number of individuals.	Length of the pupal stage in specified days.															
		15	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
Apr.	14	1												1			
	16	1												1			
	18	2										1	1				
	19	2									1					1	
	20	2														2	
	21	7												1	5	1	
	23	1											1				
	24	3									1	2					
	25	2										1		1			
	26	10									6	1	3				
	27	7										3	3	1			
	28	18									2	6	4	6			
	29	10										2	6	2			
	30	8								1		4	3				
	May	1	3									2	1				
		3	3							2		1					
		4	3							1	2						
5		1						1									
6		3				1	2										
7		15				4	11										
8		15			1	1	10		2		1						
9		7				3	1	3									
10		2				1		1									
11		21		1		1		1		5	8	4		1			
12		29							2	6	10	2					
13		17								3	12	2					
14		10								7	1	1		1			
15		6								3	3						
16		3									2	1					
17		6					1	1	1		1	2					
18		4						1		3							
21	1					1											
22	1					1											
23	3			1	1	1											
24	2			1	1												
25	1				1												
26	1					1											
27	2			1	1												
28	2			2													
30	6		6														
June 7	1	1															
	233	1	7	6	9	22	19	7	32	39	25	21	23	13	5	4	

Average length of pupal stage.....	Days. 27.58
Maximum length of pupal stage.....	34
Minimum length of pupal stage.....	15

MOTHS OF THE SPRING BROOD.

Time of emergence.—The tabulated data of the emergence of 1,539 moths of the spring brood are given in Table V. It will be noted in this table that the first moths issued May 12, while the last moth of this brood did not emerge until June 29 or nearly seven weeks later. The emergence is largely dependent upon temperature and atmospheric conditions and hence the number of moths issuing daily fluctuates more or less in accordance with the climatic factors. The number of moths appearing daily gradually increased (with

one exception) up to May 17, as shown diagrammatically in figure 2, and probably would have continued growing larger had it not been for the retarding influence of the weather, which began May 18 and continued to May 21, inclusive. The temperature dropped considerably on May 18 and was accompanied by 0.12 inch of precipitation.

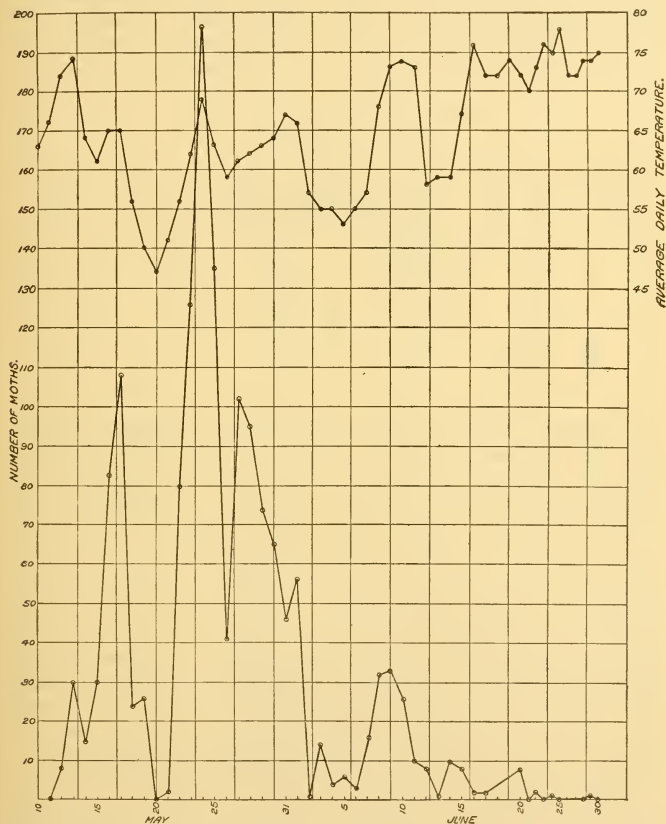


FIG. 2.—Time of emergence of moths of the spring brood of the codling moth, Grand Junction, Colo., 1915.

On the following day, May 19, the temperature dropped somewhat lower and heavy rains (0.44 inch) occurred in the afternoon and evening. The next day, May 20, was colder than the two preceding days, the maximum temperature being 58° F. and the minimum 44° F. In addition to the low temperature, it rained practically the en-

tire day, with a total of 0.29 inch of precipitation. The development and activity of the codling moth were almost completely arrested, with the result that no moths issued and no eggs were deposited. With normal temperature conditions on May 18, 19, and 20, the emergence of moths would doubtless have been large. The weather turned increasingly warmer May 22, 23, and 24, and on the latter date the maximum number of moths (196) issued. Thereafter the emergence gradually decreased, the rate conforming closely to the variations of the temperature until all of the moths had issued.

TABLE V.—*Time of emergence of codling moths of the spring brood, Grand Junction, Colo., 1915.*

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
May 12	8	May 23	126	June 2	1	June 12	8	June 22	2
13	30	24	196	3	14	13	1	23	0
14	15	25	135	4	4	14	10	24	1
15	30	26	41	5	6	15	8	25	0
16	83	27	102	6	3	16	2	26	0
17	108	28	95	7	15	17	2	27	0
18	24	29	74	8	32	18	4	28	0
19	26	30	65	9	33	19	6	29	1
20	0	31	46	10	26	20	8		
21	2	June 1	56	11	10	21	0	Total...	1,539
22	80								

Oviposition by moths of the spring brood.—In Table VI are recorded the observations of the oviposition of 1,140 female moths confined with 1,007 male moths in 92 cages. In this connection it is of interest to note the variations in the time of oviposition by the moths in the several cages. Thus, moths emerging May 12 and confined in cage 1 did not deposit eggs until May 22, whereas the moths in cage 2, although issuing a day later, commenced oviposition May 15. A more detailed study of the table will show numerous variations of the oviposition habits of the moths. A summary of the data is as follows: The number of days before oviposition averaged 6.19, the maximum was 19, and the minimum 2; the number of days for the period of oviposition averaged 13.82, maximum 33, minimum 1; the average number of days from the date of emergence to the date of last oviposition was 19.14, maximum 37, minimum 5.

Number of eggs per female moth.—It was found in the oviposition studies of the moths of the spring brood that the average number of eggs deposited was 12.59 per female moth. This number was obtained by dividing the total number of eggs deposited by the total number of female moths caged, as shown in Table VI.

TABLE VI.—Oviposition of codling moths of the spring brood in rearing cages, Grand Junction, Colo., 1915.

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male.	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition period.	From date of emergence to last oviposition.
1	29	15	14	May 12	May 22	June 1	82	10	11	20
2	20	6	14	May 13	May 15	June 9	230	2	26	27
3	24	11	13	..do....	May 24	June 3	162	11	11	21
4	28	12	16	May 14	May 17	May 31	207	3	15	17
5	25	12	13	May 15	May 18	June 15	231	3	29	31
6	25	9	16	May 16	..do....	June 11	346	2	25	26
7	25	11	14	..do....	May 21	June 22	508	5	33	37
8	24	12	12	..do....	May 22	June 7	70	6	17	22
9	19	6	13	..do....	May 23	June 4	94	7	13	19
10	23	7	16	..do....	May 28	June 2	2	12	6	17
11	34	14	20	May 17	May 22	June 14	222	5	24	28
12	23	10	13	..do....	May 24	June 1	115	7	9	15
13	22	15	7	..do....	..do....	June 11	162	7	19	25
14	27	16	11	..do....	..do....	June 15	271	7	23	29
15	25	16	9	May 18	May 25	June 13	151	7	20	26
16	28	19	9	May 19	..do....	June 17	80	6	24	29
17	8	5	3	May 21	June 9	June 10	83	19	2	20
18	22	7	15	May 22	May 24	June 14	299	2	22	23
19	25	13	12	..do....	May 25	June 11	204	3	18	20
20	27	15	12	..do....	..do....	..do....	77	3	18	20
21	16	5	11	..do....	May 29	June 9	130	7	12	18
22	21	10	11	May 23	May 25	June 15	74	2	22	23
23	25	14	11	..do....	..do....	June 17	149	2	24	25
24	23	8	15	..do....	May 27	June 8	85	4	13	16
25	21	7	14	..do....	May 31	June 17	132	8	18	25
26	12	7	5	..do....	June 9	June 23	5	17	15	31
27	24	15	9	May 24	May 27	June 19	216	3	24	26
28	28	13	15	..do....	May 31	June 20	176	7	21	27
29	23	12	11	..do....	June 1	June 8	78	8	8	15
30	24	10	14	..do....	..do....	June 11	88	8	11	18
31	20	8	12	..do....	..do....	June 19	98	8	19	26
32	26	10	16	..do....	..do....	June 25	28	8	25	32
33	26	15	11	..do....	June 3	June 23	451	10	21	30
34	23	8	15	..do....	June 6	June 19	226	13	14	26
35	24	15	9	May 25	May 28	June 18	200	3	22	24
36	24	10	14	..do....	May 30	June 17	284	5	19	23
37	21	9	12	..do....	June 1	June 19	53	7	19	25
38	23	13	10	..do....	June 9	June 15	21	15	7	21
39	22	9	13	May 26	May 31	June 19	413	5	20	24
40	20	9	11	..do....	..do....	..do....	419	5	20	24
41	30	12	18	May 27	June 1	..do....	100	5	19	23
42	25	13	12	..do....	..do....	June 6	52	5	6	10
43	21	9	12	..do....	..do....	June 18	244	5	18	22
44	22	12	10	..do....	May 31	June 16	204	4	17	20
45	24	14	10	May 28	June 1	..do....	189	4	16	19
46	24	10	14	..do....	..do....	..do....	243	4	16	19
47	22	7	15	..do....	..do....	June 19	333	4	19	22
48	22	7	15	..do....	..do....	June 26	235	4	26	29
49	25	8	17	May 29	June 2	June 18	323	4	17	20
50	31	14	17	..do....	..do....	June 28	457	4	27	30
51	21	8	13	..do....	June 4	June 16	138	6	13	18
52	19	11	8	..do....	June 7	..do....	92	9	10	18
53	23	15	8	..do....	June 10	June 11	39	12	2	13
54	20	9	11	May 30	June 4	June 19	221	5	16	20
55	26	8	18	..do....	..do....	June 22	296	5	19	23
56	25	14	11	..do....	June 7	June 17	157	8	11	18
57	23	14	9	..do....	June 9	June 22	126	10	14	23
58	23	15	8	May 31	June 7	June 7	5	7	1	7
59	20	11	9	..do....	..do....	June 17	117	7	11	17
60	26	10	16	..do....	June 9	June 14	67	9	6	14
61	21	10	11	..do....	..do....	..do....	51	9	6	14
62	24	14	10	June 1	June 7	June 16	111	6	10	15
63	22	13	9	..do....	June 10	June 19	94	9	10	18
64	27	12	15	..do....	..do....	..do....	113	9	10	18
65	11	3	8	June 2	June 11	June 12	54	9	2	10
66	23	11	12	June 3	June 9	June 16	183	6	8	13
67	11	7	4	June 4	June 10	June 11	49	6	2	7
68	6	4	2	June 5	June 11	June 22	82	6	12	17
69	19	9	10	June 6	..do....	June 21	28	5	11	15

TABLE VI.—*Oviposition of codling moths of the spring brood in rearing cages, Grand Junction, Colo., 1915—Continued.*

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male.	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition period.	From date of emergence to last oviposition.
70	23	10	13	June 7	June 11	June 20	251	4	10	13
71	25	15	10	..do....	June 16	June 16	3	9	1	9
72	27	15	12	June 8	June 11	June 27	250	3	7	19
73	22	13	9	..do....	June 18	June 21	10	10	4	13
74	22	7	15	..do....	June 21	June 25	7	13	5	17
75	31	18	13	June 9	June 16	June 26	238	7	11	17
76	29	12	17	..do....	..do....	June 27	52	7	12	18
77	33	13	20	June 10	June 12	June 23	211	2	12	13
78	31	21	10	..do....	..do....	June 26	100	2	15	16
79	31	18	13	..do....	June 15	June 25	367	5	11	15
80	38	16	22	June 11	June 16	..do....	134	5	10	14
81	29	14	15	June 12	..do....	June 23	275	4	8	11
82	9	1	8	June 13	June 19	June 21	7	6	3	8
83	20	10	10	June 14	..do....	..do....	11	..	..	..
84	30	13	17	June 15	June 18	June 29	54	3	12	14
85	32	11	21	June 16	June 19	June 26	129	3	8	10
86	30	13	17	June 17	..do....	July 3	293	2	15	16
87	25	7	18	June 18	June 22	June 30	92	4	9	12
88	25	10	15	..do....	June 23	July 1	202	5	9	13
89	24	10	14	June 19	June 24	July 4	152	5	11	15
90	25	11	14	June 20	June 22	July 1	182	2	10	11
91	12	4	8	June 21	..do....	..do....	0	..	..	..
92	9	3	6	June 22	June 27	June 27	24	5	1	5
Average								6.19	13.82	19.14
Maximum								19	33	37
Minimum								2	1	5

¹ Deposited on side of cage.

Number of male moths.....	1,007
Number of female moths.....	1,140
Total number of moths.....	2,147
Total number of eggs.....	14,359
Average number of eggs per female moth.....	12.59

Length of life of moths.—The dead moths in the oviposition cages were removed each day; their sex was then determined and the length of their life computed. The results of these observations are given in Table VII, in which it will be found that the average length of life of 1,283 male moths was 14.59 days and of 1,462 female moths 15.86 days; the maximum length of life of the male moths was 36 days, of the female moths 39 days; the minimum length of life of the male moths was 1 day, of the female moths 1 day.

TABLE VII.—Length of life of male and female codling moths of the spring brood in captivity: Summary of records of 2,745 individual moths, Grand Junction, Colo., 1915.

Male.		Female.		Male.		Female.		Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.
<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	
1	9	1	5	15	61	15	95	29	8	29	15
2	9	2	3	16	58	16	99	30	11	30	6
3	4	3	5	17	58	17	88	31	4	31	4
4	14	4	11	18	50	18	73	32	6	32	5
5	29	5	12	19	41	19	72	33	5	33	10
6	46	6	18	20	65	20	91	34	3	34	2
7	63	7	41	21	43	21	69	35	2	35	3
8	79	8	39	22	38	22	36	36	1	36	0
9	49	9	72	23	26	23	37	37	0	37	0
10	77	10	77	24	27	24	33	38	0	38	1
11	65	11	79	25	21	25	28	39	0	39	1
12	71	12	88	26	25	26	24				
13	99	13	97	27	10	27	14				
14	79	14	98	28	17	28	11	Total.	1,283	Total.	1,462

Average length of life of male moths, 14.59 days; female moths, 15.86 days.

Maximum length of life, male moths, 36 days; female moths, 39 days.

Minimum length of life of male moths, 1 day; female moths, 1 day.

THE FIRST GENERATION.

EGGS OF THE FIRST BROOD.

Time of egg deposition.—The first eggs of this brood were deposited on May 13 in a cage in which were confined some of the earliest moths of the spring brood, emerging on different dates. The deposition of the eggs, as shown in Table VIII, continued daily

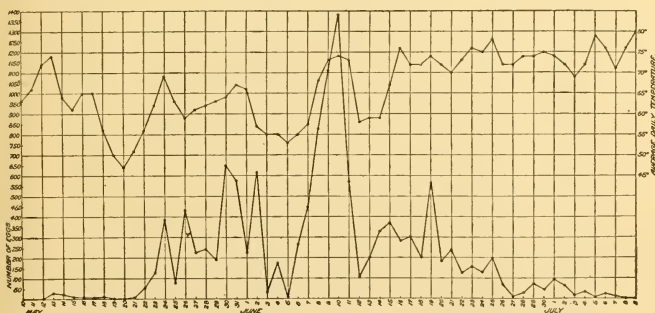


FIG. 3.—Time of deposition of eggs of the first brood of the codling moth, Grand Junction, Colo., 1915.

up to and including July 8, with the exception of May 19 and 20, on which days no eggs were laid owing to the unfavorable weather conditions previously mentioned (see p. 13). The greatest number of eggs deposited on any one day was 1,379, as will be noted in the

graph, figure 3. By further reference to this figure it will be seen that the average daily temperatures from June 3 to June 7 were relatively low and that during this period the moths did not deposit very freely. With the rise in temperature from June 7 to 10, the moths were much more active and deposited 828 eggs on June 8, 1,106 eggs on June 9, and the maximum number of eggs, 1,379, on June 10. The average temperature was also high on June 11, but the deposition of eggs was notably less than on the preceding days. Following the crest of egg deposition, the number daily deposited gradually diminished, except on June 19, when 564 eggs were laid.

TABLE VIII.—*Time of deposition, length of incubation, and time of hatching of eggs of the first brood of the codling moth, Grand Junction, Colo., 1915.*

Observation.	Number of eggs.	Date—				Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.	Red ring.	Black spot.	
						Days.	Days.	Days.
1	15	May 13	May 16	May 25	May 27	3	12	14
2	10	do.	do.	do.	May 28			15
3	2	May 14	May 16	May 27	do.	2	13	14
4	20	do.	do.	do.	May 29			15
5	5	May 15	May 17	May 28	do.	2	13	14
6	1	do.	do.	do.	May 30			15
7	4	May 16	May 22	May 29	do.	6	13	14
8	2	do.	do.	do.	May 31			15
9	1	May 17	May 23	May 30	do.	6	13	14
10	5	do.	do.	do.	June 1			15
11	8	May 18	May 27	May 31	do.	9	13	14
12	2	do.	do.	do.	June 2			15
13	5	May 21	May 27	May 31	June 1	6	10	11
14	39	May 22	May 28	do.	June 2	6	9	11
15	12	do.	do.	do.	June 3			12
16	1	do.	do.	do.	June 4			13
17	1	do.	do.	do.	June 5			14
18	45	May 23	May 28	June 1	June 2	5	9	10
19	22	do.	do.	do.	June 3			11
20	34	do.	do.	do.	June 4			12
21	14	do.	do.	do.	June 5			13
22	3	do.	do.	do.	June 6			14
23	7	do.	do.	do.	June 7			15
24	20	May 24	May 29	June 1	June 4	5	8	11
25	136	do.	do.	do.	June 5			12
26	140	do.	do.	do.	June 6			13
27	65	do.	do.	do.	June 7			14
28	19	May 25	May 29	June 4	do.	4	10	13
29	42	do.	do.	do.	June 8			14
30	8	do.	do.	do.	June 9			15
31	284	May 26	May 30	June 4	June 8	4	9	13
32	90	do.	do.	do.	June 9			14
33	2	May 27	May 31	June 7	June 8	4	11	12
34	187	do.	do.	do.	June 9			13
35	157	May 28	May 31	June 7	do.	3	10	12
36	41	do.	do.	do.	June 10			13
37	5	do.	do.	do.	June 11			14
38	120	May 29	June 1	June 8	June 10	3	10	12
39	51	do.	do.	do.	June 11			13
40	162	May 30	June 3	June 9	June 10	4	10	11
41	299	do.	do.	do.	June 11			12
42	19	do.	do.	do.	June 12			13
43	367	May 31	June 3	June 10	June 11	3	10	11
44	57	do.	do.	do.	June 12			12
45	11	do.	do.	do.	June 13			13
46	7	June 1	June 4	June 10	June 12	3	9	11
47	161	do.	do.	do.	June 13			12
48	2	do.	do.	do.	June 14			13
49	324	June 2	June 8	June 11	June 13	6	9	11
50	43	do.	do.	do.	June 14			12
51	30	do.	do.	do.	June 15			13
52	6	June 3	do.	June 11	June 14		8	11
53	29	do.	do.	do.	June 15			12

TABLE VIII.—*Time of deposition, length of incubation, and time of hatching of eggs of the first brood of the codling moth, Grand Junction, Colo., 1915—Con.*

Observation.	Number of eggs.	Date—				Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.	Red ring.	Black spot.	
						<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
54	46	June 4	June 9	June 11	June 14	5	7	10
55	81	do.	.....	.....	June 15	3	.....	11
56	4	June 5	.....	June 13	June 15	.....	8	10
57	1	do.	.....	.....	June 16	.....	.....	11
58	1	do.	.....	.....	June 17	.....	.....	12
59	163	June 6	June 10	June 12	June 15	4	6	9
60	55	do.	.....	.....	June 16	.....	.....	10
61	49	June 7	June 10	June 12	June 15	3	5	8
62	284	do.	.....	.....	June 15	.....	.....	9
63	215	June 8	June 10	June 14	June 17	2	6	9
64	191	do.	.....	.....	June 18	.....	.....	10
65	619	June 9	June 11	June 16	June 17	2	7	8
66	55	June 10	June 12	do.	June 17	2	6	7
67	690	do.	.....	.....	June 18	2	6	8
68	69	do.	.....	.....	June 19	.....	.....	9
69	233	June 11	June 15	June 18	do.	4	7	8
70	85	do.	.....	.....	June 20	.....	.....	9
71	76	June 12	June 16	June 18	do.	4	6	8
72	12	do.	.....	.....	June 21	.....	.....	9
73	102	June 13	June 16	June 19	June 20	3	6	7
74	69	do.	.....	.....	June 21	.....	.....	8
75	241	June 14	June 17	June 19	do.	3	5	7
76	56	do.	.....	.....	June 22	.....	.....	8
77	237	June 15	June 17	June 20	do.	2	5	7
78	11	do.	.....	.....	June 23	.....	.....	8
79	245	June 16	June 18	June 21	do.	2	5	7
80	20	do.	.....	.....	June 24	.....	.....	8
81	248	June 17	June 19	June 22	June 23	2	5	6
82	12	do.	.....	.....	June 24	.....	.....	7
83	141	June 18	June 21	June 24	June 25	3	6	7
84	49	do.	.....	.....	June 25	.....	.....	8
85	502	June 19	June 21	June 24	do.	2	5	7
86	149	June 20	June 22	June 25	do.	2	5	6
87	25	do.	.....	.....	June 27	.....	.....	7
88	198	June 21	June 22	June 28	June 28	1	5	7
89	31	do.	.....	.....	June 29	1	5	8
90	117	June 22	June 23	June 27	June 28	.....	.....	6
91	5	do.	.....	.....	June 29	1	5	7
92	145	June 23	June 24	June 28	June 30	1	5	8
93	3	do.	.....	.....	July 1	.....	.....	6
94	13	June 24	June 25	June 29	June 30	1	5	7
95	111	do.	.....	.....	July 1	.....	.....	7
96	191	June 25	June 26	June 30	July 1	1	5	7
97	2	do.	.....	.....	July 2	3	.....	8
98	65	June 26	June 28	July 1	do.	2	5	7
99	4	do.	.....	.....	July 4	.....	.....	8
100	11	June 27	June 29	July 2	do.	2	5	7
101	27	June 28	June 30	July 3	do.	2	5	6
102	1	do.	.....	.....	July 5	.....	.....	7
103	74	June 29	July 1	July 3	do.	2	4	6
104	35	June 30	July 2	July 4	July 6	2	4	6
105	7	do.	.....	.....	July 7	.....	.....	7
106	94	July 1	July 2	July 6	July 8	1	5	7
107	63	July 2	July 4	July 7	July 9	2	5	7
108	1	do.	.....	.....	July 10	.....	.....	8
109	16	July 3	July 6	July 8	July 10	3	5	7
110	33	July 4	do.	July 10	July 11	2	6	7
111	1	do.	.....	.....	July 12	.....	.....	8
112	17	July 5	do.	July 11	do.	1	6	7
113	24	July 6	July 8	July 12	July 13	2	6	7
114	11	July 7	do.	.....	.....	1	.....	.....
115	11	July 8	.....	.....	.....	.....	.....	.....
Ave.....						2.70	6.62	9.14
Max.....						9	13	15
Min.....						1	4	6

¹ Eggs not included in averages due to failure to develop fully.

Length of incubation.—As will be noted in Table VIII, the earliest eggs required an incubation period about twice as long as those deposited later. This is accounted for by the lower temperatures to which the earlier eggs were subjected. The incubation period gradually decreased as the daily temperatures became higher with the advance of the season. The average number of days from the date of deposition to the time of the appearance of the red ring was 2.70, maximum 9 days, minimum 1 day; the average number of days from the date of deposition to the black-spot stage was 6.62, maximum 13 days, minimum 4 days; the average incubation period was 9.14 days, maximum 15 days, minimum 6 days.

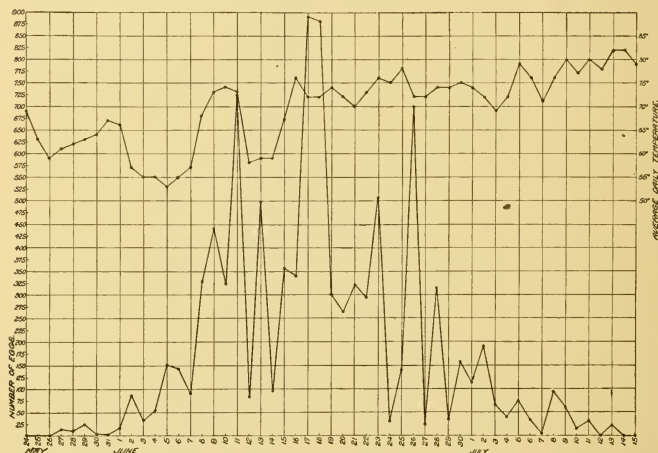


FIG. 4.—Time of hatching of eggs of the first brood of the codling moth, Grand Junction, Colo., 1915.

LARVÆ OF THE FIRST BROOD.

Time of hatching.—Larvæ of the first brood commenced to hatch on May 27 and continued to hatch until July 13, as given in the complete hatching data in Table VIII. The eggs were hatching in maximum numbers on June 17, just one week after the time when the greatest number of eggs was deposited. The interval from the date of the appearance of the first larva to the time of hatching of the larvæ in maximum numbers was 21 days. This interval would probably have been reduced somewhat had the weather been warmer on June 12, 13, and 14. The time of hatching of the eggs of the first brood is presented graphically in figure 4.

Length of the feeding period, stock-jar method.—The length of the feeding period of 758 larvæ of the first brood (both transforming

and nontransforming) according to the stock-jar method (see p. 8) is given in Table IX. As will be observed, the length of the feeding period averaged 21.64 days, maximum 35 days, minimum 12 days.

Length of the feeding period, bagged-fruit method.—In Table X will be found the results of the observations of the feeding period of 242 larvæ of the first brood (both transforming and nontransforming) by means of the bagged-fruit method (see p. 8). The average period of feeding was 22.77 days, maximum 35 days, minimum 15 days.

TABLE IX.—*Length of feeding period of larvæ of the first brood of the codling moth, stock-jar method, Grand Junction, Colo., 1915.*

Date of entering fruit.	Number of individuals.	Length of feeding period in specified days.																																		
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35											
May 27	1																1																			
	2												2																							
29	1													1																						
30	5										1	1	3																							
June 5	16								1	4	6	1	1	1	2																					
	3									2																										
6	7																																			
7	4																																			
8	9							1	3	4				1																						
9	19						1	2	3	1	6	4	1																							
10	39						1		5	6	7	7	2	3	4	2	1			1																
11	6							1	1		1	1	2																							
12	9					1	1	2	4	2	2	3	4	1	1	2	2																			
13	27					1	5	3	6	4	11	3	4	1	1	2	2																			
14	59	1	1	1	5	11	5	3	6	4	11	3	4	1	1	2	1			1																
15	41				2	1	4	2	3	4	4	6	5	2	2	2	4			4	1															
16	52				1	1	1	8	9	5	6	4	7	2	7	2	6			1																
17	68				1	2	1	7	7	7	9	10	3	9	2	2	5			2	5															
18	50								8	6	9	9	6	3		4				1																
19	25						2	1		3	4	2	5	2	2				1	1	1															
20	29							1	4	5	5			5		2	5			2	5															
21	18							2		4	1	1	1	1	1	2			2	1																
22	23							2	3	3			4	5	2	2			1	1																
23	24							2	4	1			2	5	2				1	2	2															
24	25						2	2	2							1			1	2																
25	13															1			1																	
26	24						1	3	5			2		5		4	2		1	2																
27	24						2	2	1	5	4		4		1	1			1	1																
28	34				1	2		1	4		2	5	4	4		5			1	1																
29	15			2				5	3		3																									
30	10					1	2	2	2		2			1																						
July 1	12				1	4					1	1				4																				
	2				2	1		6	1	1	3					3																				
3	13				3	2	1	1	2	1																										
4	2					1		1																												
5	8					1		1	2	2			1			1																				
6	9					1	2	1	2			2		2		1																				
7	6	1					1	1	1	1																										
8	17					3	1		2	2	3		1		1				2																	
9	14				1		2	1	2	3																										
10	3			1				1																												
11	3					1					1																									
12	2						2																													
13	1							1																												
758		1	1	1	7	25	44	69	89	83	94	73	68	57	34	32	27	13	12	8	6	5	5	2	2											

Days.

Average length of feeding period..... 21.64
Maximum length of feeding period..... 35
Minimum length of feeding period..... 12

TABLE X.—Length of feeding period of larvæ of the first brood of the codling moth, bagged-fruit method, Grand Junction, Colo., 1915.

Date of entering fruit.	Number of individuals.	Length of feeding period in specified days.																																	
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35													
May 31 June 2 3 4 11 5 6 14 7 8 11 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 July 1 2 3	1																																		
	1											1							1																
	8												1																						
	11										3																								
	6									2	1	1																							
	14									9	2	1																							
	7								1	7	1		2	1	1																				
	8																																		
	11								1	3		1		1	2	1																			
	10	6				2			2			1																					2		
	11	4			2			1		1																									
	12	1																																	
	13	6				1	3					1		1																					
	14	8																																	
	15	5								2	2	3																							
	16	6								2	2																								
	17	8		1						2																									
	18	11																																	
	19	5																																	
	20	3																																	
	21	12																																	
	22	1																																	
	23	10	1			1																													
	24	8																																	
	25	7																																	
	26	7																																	
	27	6																																	
	28	11	1			1		3	1			2	1	2																					
	29	6																																	
	30	6																																	
	31	8																																	
July 1	7																																		
2	18																																		
3	7																																		
		242	2	3	1	17	13	26	53	19	20	21	17	11	10	8	11	1	2	3	1	1	2												

Days.

Average length of feeding period..... 22.7

Maximum length of feeding period..... 35

Minimum length of feeding period..... 15

Length of the cocooning period.—The cocooning period is herein considered as extending from the time the larva leaves the fruit until it has pupated. The data given in Table XI, therefore, apply only to the transforming larvæ of the first brood. By reference to this table it will be seen that the cocooning period was recorded for 430 individuals which left the fruit from June 23 to July 26. Of this number, 86 formed their cocoon in 4 days, 85 in 5 days, and 67 in 6 days. The average number of days for all individuals was 6.70, maximum 28, and minimum 1. This minimum cocooning period of 1 day is the shortest period recorded for any larva throughout this and the following season. The cocoon was of normal size, but was constructed very lightly.

TABLE XI.—Length of cocooning period of transforming codling moth larvæ of the first brood, Grand Junction, Colo., 1915.

Larvæ left fruit.	Number of individuals.	Length of cocooning period in specified days, being the time from leaving the fruit to the time of pupation.																										Av.	Max.	Min.
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18	19	20	22	23	26	28						
June	23	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4.00	4	4		
	25	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6.00	6	6		
	26	10	...	...	3	3	3	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	5.60	11	4		
	27	21	...	...	2	10	6	...	1	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4.71	8	3		
	28	18	...	...	2	3	8	...	2	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5.22	8	3		
	29	14	...	...	1	1	3	4	...	3	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5.43	9	2		
	30	10	...	...	...	2	2	2	...	3	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	6.60	12	4		
	July	1	31	1	1	7	9	6	4	1	...	...	...	...	...	...	1	1	...	...	...	...	...	...	...	...	5.87	17	2	
	2	27	1	...	1	7	6	6	2	2	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	5.55	11	1	
	3	17	...	...	1	2	3	4	4	...	1	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	7.82	28	3	
4	17	...	...	1	...	2	3	2	2	1	2	1	1	...	1	1	...	...	1	...	...	...	...	...	...	8.00	19	2		
5	17	...	...	...	2	2	2	2	2	1	...	1	1	1	...	...	...	...	1	2	1	...	...	...	...	10.70	23	4		
6	35	...	...	4	8	6	5	3	...	1	1	...	1	2	1	...	2	...	...	...	...	...	...	...	...	7.31	26	3		
7	18	...	...	...	6	2	3	3	2	...	...	...	...	2	2	...	...	...	...	...	...	...	...	...	...	6.39	13	4		
8	28	...	...	3	3	6	6	...	...	3	2	2	2	1	1	...	1	...	...	...	...	...	...	...	...	7.00	15	3		
9	20	...	...	1	2	4	2	3	2	1	3	...	1	...	1	...	...	...	...	...	...	...	...	...	...	7.25	14	3		
10	14	...	...	...	3	2	...	1	3	3	...	...	2	...	...	...	1	...	...	...	...	...	...	...	...	8.64	22	4		
11	15	...	...	1	2	...	3	3	3	...	...	2	...	...	...	...	1	...	...	...	...	...	...	...	...	7.33	15	2		
12	17	...	...	1	2	3	1	4	...	2	2	...	...	2	...	...	...	...	...	...	...	...	...	...	...	7.29	13	3		
13	8	...	...	...	2	...	2	...	2	1	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	7.25	10	4		
14	10	...	...	...	2	2	1	2	1	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6.20	9	4		
15	13	...	...	...	1	3	1	3	2	...	2	1	...	1	...	...	...	...	...	...	...	...	...	...	...	7.15	11	4		
16	10	...	...	...	4	2	2	...	...	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	6.00	12	4		
17	10	...	...	1	1	...	3	1	2	...	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	7.20	13	3		
18	10	...	...	1	2	2	1	...	2	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5.50	10	2		
19	9	...	...	1	1	3	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5.11	6	3		
20	11	...	...	2	1	3	1	...	2	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	6.27	12	3		
21	5	...	...	...	2	1	1	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	5.00	11	4		
22	6	...	...	...	1	...	2	...	2	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	7.50	13	4		
23	2	...	...	...	...	1	...	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7.00	8	6		
24	2	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6.50	8	5		
25	1	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4.00	4	4		
26	2	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6.00	6	6		
Total.	430	1	5	23	86	85	67	44	37	15	17	13	8	9	3	5	3	1	1	1	3	1	1	1	1	6.70	28	1		

PUPE OF THE FIRST BROOD.

Time of pupation.—The earliest pupation of the transforming larvæ of the first brood occurred June 27, and the latest took place August 4. The larvæ were therefore pupating during a period of slightly more than one month. See Table XII and diagram, figure 5.

Length of pupal stage.—The average length of the pupal stage of pupæ of the first brood is considerably shorter (about 16 days) than that of the spring-brood pupæ, owing to the higher temperatures prevailing during midsummer. As given in Table XIII the average length of the first-brood pupal stage was 11.44 days, maximum 31 days, and minimum 6 days.

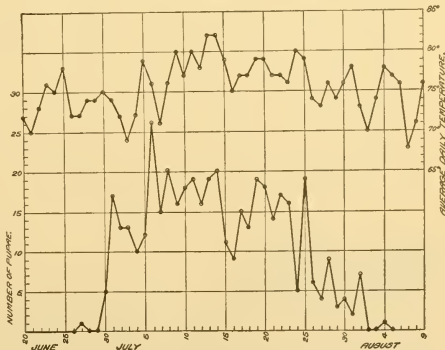


FIG. 5.—Time of pupation of first brood of the codling moth, Grand Junction, Colo., 1915.

TABLE XII.—*Time of pupation of transforming larvæ of the first brood of the codling moth, Grand Junction, Colo., 1915.*

Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.
June 27	1	July 7	15	July 15	11	July 23	16	July 31	2
30	5	8	20	16	9	24	5	Aug. 1	7
July 1	17	9	16	17	15	25	19	2	0
2	13	10	18	18	13	26	6	3	0
3	13	11	19	19	19	27	4	4	1
4	10	12	16	20	18	28	9	Total.....	432
5	12	13	19	21	14	29	3		
6	26	14	20	22	17	30	4		

TABLE XIII.—*Length of the pupal stage of pupæ of the first brood of the codling moth, Grand Junction, Colo., 1915.*

Date of pupa- tion.	Num-ber of indi- vid-uals.	Length of the pupal stage in specified days.																											
		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	24	25	31									
June 27	1							1																					
30	4						4																						
July 1	15			1		8	3	3																					
2	11				1	3	5		2				2																
3	12			1	1	5	2	3																					
4	6				2	2	1	1					1																
5	11			1		1	6	2	1				1																
6	19		1		3	6	5	5	4																				
7	13	1			1	1	8	1	1				1																
8	16			2		6	5	5	3																				
9	8			1	1	2	2	1																			1		
10	15					3	4	5	2																				
11	16				2	3	4	4		1				1													1		
12	12		1		1	2	2	4	2																		1		
13	11					1	6	5		2				2															
14	17					2	10	2	1	1						1													
15	7					1	1	5								1													
16	7				1		3	1	2																				
17	13			1		2	3	3	3																				
18	10					2	2	2	3	1																			
19	17					3	4	4	1	2				2															
20	15						4	7	2		2				2														
21	12					3	3	2		4					4														
22	12			1	1	1	2	3	3		1				1														
23	7						2	2	2	1																			
24	4						3	1																					
25	14				1	1	7	1	3	1					1														
26	4					3		1																					
27	3						1	1	1				1																
28	6					1	2	1					1		1														
29	2							2																					
30	2				1			1																					
31	2				1	1																							
Aug. 1	4			2						1					1														
	331	1	2	12	19	62	106	74	26	13	4	2	1	1	2	2	1	1	1	1									

Days.

Average length of the pupal stage 11.44
 Maximum length of the pupal stage 31
 Minimum length of the pupal stage 6

MOTHS OF THE FIRST BROOD.

Time of emergence.—The records of the time of emergence of moths of the first brood were taken from two sources of material: (1) From moths that issued from first-brood larvæ reared in the insectary and (2) from moths that issued from the larvæ collected every

three days from banded apple trees in the Hamilton orchard. The first of these sources was used primarily as a means of establishing the approximate emergence limits of the first-brood moths, while the moths that issued up to August 19 from the larvæ collected in the Hamilton orchard were used for the oviposition study of the first brood. The latter moths were employed for this purpose because their relative rate of emergence approaches normal field conditions more closely than that of the moths from the insectary reared larvæ.

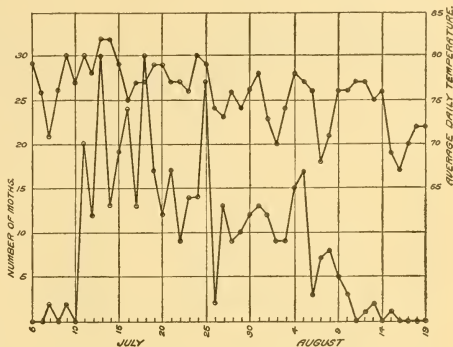


FIG. 6.—Time of emergence of moths of the first brood of the codling moth, Grand Junction, Colo., 1915.

According to the insectary-bred material, the first moth appeared July 7 and the emergence continued daily, except on a few days, to August 15. (See Table XIV and fig. 6.)

TABLE XIV.—Time of emergence of codling moths of the first brood, from material reared at the insectary, Grand Junction, Colo., 1915.

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
July 7	2	July 19	17	July 29	10	Aug. 7	7
9	2	20	12	30	12	8	8
11	20	21	17	31	13	9	5
12	12	22	9	Aug. 1	12	10	3
13	30	23	14	2	9	12	1
14	13	24	14	3	9	13	2
15	19	25	27	4	15	15	1
16	24	26	2	5	17		
17	13	27	13	6	3	Total..	426
18	30	28	9				

As given in Table XXV, the first moth of the second brood issued August 23, thus leaving a period from August 16 to 22, inclusive, during which no moths issued from larvæ reared at the insectary.

This condition did not obtain with the material from the Hamilton orchard on account of the much larger number of individuals involved, but instead moths issued continuously during the foregoing period as would naturally occur in the field. During the interval August 16 to 22 there was probably an overlapping of the broods

and, for this reason, it was impossible to determine from field material when the last moth of the first brood emerged and when the

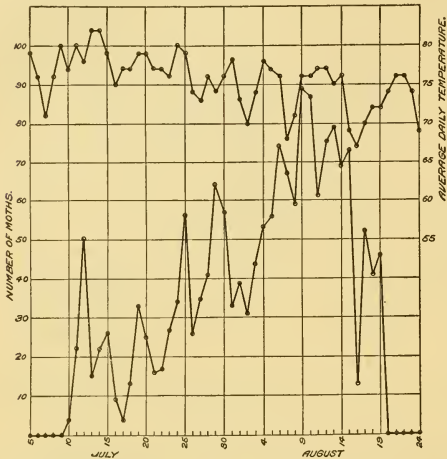


FIG. 7.—Time of emergence of moths of the first brood of the codling moth, Hamilton orchard, Grand Junction, Colo., 1915.

ure 7. According to these data the first moths emerged in maximum numbers on August 9.

first moth of the second brood appeared. It is reasonable to infer, however, that the approximate division of the broods occurred during the period of overlapping, and for this reason August 19 was selected as the end of the emergence of the first brood of moths. The time of emergence of the moths of the first brood from the larvæ collected in the Hamilton orchard is given in Table XV and presented graphically in fig-

ure 7. According to these data the first moths issued July 10, and emerged in maximum numbers on August 9.

TABLE XV.—Time of emergence of codling moths of the first brood, reared from field material, Grand Junction, Colo., 1915.

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
July 10	4	July 21	16	Aug. 1	39	Aug. 12	75
11	22	22	17	2	31	13	79
12	50	23	27	3	44	14	69
13	15	24	34	4	53	15	73
14	22	25	56	5	56	16	13
15	26	26	26	6	74	17	52
16	9	27	35	7	67	18	41
17	4	28	41	8	59	19	46
18	13	29	64	9	89		
19	33	30	57	10	87	Total..	1,737
20	25	31	33	11	61		

Number of eggs per female moth.—It will be observed in Table XVI that the total number of eggs deposited by the 945 female moths of the first brood was 44,158 or 46.73 eggs per female moth. This average is nearly four times greater than that made by the spring-brood moths (12.59 eggs) owing, doubtless, to the more favorable climatic factors during the oviposition period of the first-brood moths.

TABLE XVI.—*Oviposition by codling moths of the first brood in rearing cages, Grand Junction, Colo., 1915.*

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male.	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	From first to last oviposition.	From date of emergence to last oviposition.
1	24	10	14	July 12	July 13	July 24	797	1	12	12
2	26	17	9	do	July 14	July 25	679	2	12	13
3	15	11	4	July 13	do	do	501	1	12	12
4	22	11	11	July 14	July 16	July 24	390	2	9	10
5	26	14	12	July 15	do	July 28	351	1	13	13
6	9	7	2	July 16	do	do	(1)			
7	4	2	2	July 17	July 20	July 31	74	3	12	14
8	13	3	10	July 18	do	Aug. 1	667	2	13	14
9	33	11	22	July 19	do	Aug. 5	1,475	1	17	17
10	25	12	13	July 20	July 22	Aug. 14	624	2	24	25
11	16	8	8	July 21	July 23	Aug. 5	767	2	14	15
12	17	9	8	July 22	July 24	Aug. 6	684	2	14	15
13	27	14	13	July 23	July 25	Aug. 18	427	2	25	26
14	34	12	22	July 24	do	Aug. 10	1,089	1	17	17
15	26	11	15	July 25	July 27	Aug. 13	860	2	18	19
16	30	15	15	do	do	Aug. 12	662	2	17	18
17	26	13	13	July 26	July 28	Aug. 8	602	2	12	13
18	35	12	23	July 27	July 29	Aug. 18	1,127	2	21	22
19	19	4	15	July 28	July 30	do	776	2	20	21
20	22	9	13	do	do	do	640	2	20	21
21	33	15	18	July 29	July 31	Aug. 14	517	2	15	16
22	31	10	21	do	do	Aug. 21	723	2	22	23
23	29	16	13	July 30	Aug. 1	Aug. 25	700	2	25	26
24	28	6	22	do	July 31	Aug. 19	737	1	20	20
25	12	6	6	July 31	Aug. 2	Aug. 16	229	2	15	16
26	21	8	13	do	Aug. 1	Aug. 20	641	1	20	20
27	18	7	11	Aug. 1	Aug. 5	Aug. 18	114	4	14	17
28	21	11	10	do	Aug. 4	do	382	3	15	17
29	31	13	18	Aug. 2	do	Aug. 26	694	2	23	24
30	22	8	14	Aug. 3	Aug. 5	Aug. 17	512	2	13	14
31	22	7	15	do	Aug. 6	Aug. 25	465	3	20	22
32	23	10	13	Aug. 4	do	Aug. 28	1,068	2	23	24
33	30	13	17	do	do	Aug. 22	903	2	17	18
34	30	14	16	Aug. 5	do	Aug. 27	703	1	22	22
35	26	16	10	do	do	Aug. 23	668	1	18	18
36	25	8	17	Aug. 6	Aug. 11	Aug. 22	171	5	12	16
37	22	8	14	do	Aug. 8	Aug. 24	1,185	2	17	18
38	27	17	10	do	Aug. 10	Aug. 25	200	4	16	19
39	35	18	17	Aug. 7	Aug. 9	Aug. 26	742	2	18	19
40	32	13	19	do	do	Aug. 28	1,434	2	20	21
41	34	15	19	Aug. 8	Aug. 10	Aug. 25	1,393	2	16	17
42	25	15	10	do	do	Aug. 29	684	2	20	21
43	26	13	13	Aug. 9	Aug. 11	Aug. 26	568	2	16	17
44	36	18	20	do	do	Aug. 22	990	2	12	13
45	27	12	15	do	Aug. 10	Aug. 28	838	1	19	19
46	34	14	20	Aug. 10	Aug. 12	Aug. 30	755	2	19	20
47	27	10	17	do	do	Aug. 26	350	2	15	16
48	26	17	9	do	do	Aug. 24	1,000	2	13	14
49	31	14	17	Aug. 11	Aug. 13	Sept. 2	622	2	21	22
50	30	16	14	do	do	Aug. 27	980	2	15	16
51	24	14	10	Aug. 12	Aug. 14	Aug. 28	436	2	15	16
52	29	9	20	do	do	do	701	2	15	16
53	22	6	16	do	Aug. 13	Aug. 31	456	1	19	19
54	27	10	17	Aug. 13	Aug. 15	Aug. 29	357	2	15	16
55	26	11	15	do	Aug. 16	Aug. 28	756	3	13	15
56	26	13	13	do	Aug. 15	do	591	2	14	15
57	24	14	10	Aug. 14	Aug. 19	Sept. 1	372	5	14	18
58	23	6	17	do	Aug. 16	Aug. 31	583	2	16	17
59	22	8	14	do	Aug. 15	Aug. 29	700	1	15	15
60	25	10	15	Aug. 15	Aug. 17	Sept. 9	1,103	2	24	25
61	22	11	11	do	Aug. 18	Sept. 1	749	3	15	17
62	26	11	15	do	Aug. 17	Sept. 2	403	2	17	18
63	13	5	8	Aug. 16	Aug. 21	Aug. 27	29	5	7	11
64	25	12	13	Aug. 17	Aug. 18	Sept. 1	299	1	15	15
65	27	16	11	do	Aug. 19	Aug. 28	473	2	10	11
66	21	9	12	Aug. 18	Aug. 20	Sept. 7	502	2	19	20
67	20	9	11	do	do	Sept. 12	639	2	24	25
68	22	12	10	Aug. 19	Aug. 22	Sept. 7	340	3	17	19
69	24	9	15	do	Aug. 20	Sept. 12	565	1	24	24
Average.....								2.07	16.78	17.85
Maximum.....								5	25	26
Minimum.....								1	7	10

¹ No eggs.

Number of male moths.....	766	Total number of eggs.....	44,158
Number of female moths.....	945	Average number of eggs per female moth....	46.73
Total number of moths.....	1,711		

Time of oviposition.—One of the most important problems in connection with the control of the codling moth in the Grand Valley was to determine when the earliest eggs of the second brood were deposited and when oviposition was at its height. It is believed that these data could best be secured by using moths that emerged from larvæ collected regularly from banded orchard trees, since the subsequent emergence of the moths would correspond to that which would naturally have occurred in the field. With this in view, the moths from the Hamilton orchard material were kept for oviposition studies, beginning with those that emerged July 12 and ending with those that issued August 19.

As is given in Table XVI, 69 cages containing a total of 1,711 moths were employed and, as will be noted therein, the average number of days before oviposition was 2.07, maximum 5, and minimum 1; the average number of days from the first to the last oviposition was 16.78, maximum 25, and minimum 7; the average number of days from the date of emergence to last oviposition was 17.85, maximum 26, and minimum 10.

According to this table the first eggs were deposited July 13 by moths that emerged July 12 and the last eggs were laid September 12. A few moths issued July 10 and 11 from the Hamilton orchard material, and, in addition to these, several moths emerged from insectary-bred and other material as early as July 7. These moths were confined together in a cage and deposited the earliest second-brood eggs on July 11, as shown in figure 8, page 31.

Length of life of moths.—Table XVII includes the summary of records of the length of life of 1,719 male and female moths of the first brood. The data in this table show that the average length of life of 769 male moths was 11.86 days, of 950 female moths 12.68 days; the maximum length of life of male moths 41 days, of female moths 35 days; the minimum length of life of male moths 1 day, of female moths 1 day. As has been frequently observed in other studies of the life history of the codling moth with but few exceptions, the average life of the female moth is longer than that of the male.

TABLE XVII.—*Length of life of male and female codling moths of the first brood in captivity; summary of records of 1,719 individual moths, Grand Junction, Colo., 1915.*

Male.		Female.		Male.		Female.		Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.
<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	
1	4	1	1	16	26	16	64	31	1	31	0
2	8	2	2	17	29	17	39	32	0	32	0
3	24	3	10	18	27	18	36	33	0	33	0
4	15	4	10	19	10	19	21	34	0	34	0
5	44	5	16	20	12	20	20	35	0	35	1
6	48	6	35	21	16	21	13	36	1	36	0
7	55	7	35	22	7	22	16	37	1	37	0
8	55	8	61	23	6	23	7	38	1	38	0
9	38	9	72	24	7	24	7	39	0	39	0
10	68	10	75	25	8	25	3	40	0	40	0
11	49	11	103	26	7	26	5	41	1	41	0
12	58	12	96	27	4	27	3	Total.		Total.	
13	45	13	74	28	3	28	3				
14	39	14	65	29	2	29	3				
15	46	15	54	30	4	30	0				

Average length of life of male moths, 11.86 days; female moths, 12.68 days.

Maximum length of life of male moths, 41 days; female moths, 35 days.

Minimum length of life of male moths, 1 day; female moths, 1 day.

LIFE CYCLE OF THE FIRST GENERATION.

Life cycle, stock-jar feeding method.—The length of the life cycle of the first generation of the codling moth, by the stock-jar feeding method, is given in Table XVIII and, as shown therein, includes the time from the deposition of the egg to the emergence of the moth. The complete life cycle extends from the deposition of the eggs of one generation to the deposition of the eggs of the next, and it will therefore be necessary to add 2.07 days, the average number of days from emergence of moth to first oviposition, to the figures in Table XVIII to determine the complete life cycle. It will be noted in this table that the data include 221 individuals, giving the incubation period, and the average, maximum, and minimum length of the larval feeding period, the cocooning period, the pupal period, and the life cycle. The summarized averages are: Incubation period 9.91 days, larval feeding period 20.75 days, cocooning period 6.99 days, pupal period 11.64 days, and life cycle 49.30 days, complete life cycle 51.37 days.

Life cycle, bagged-fruit feeding method.—In Table XIX the life cycle of the first generation of the codling moth, by the bagged-fruit method, is given for 109 individuals. The summarized average figures are: Incubation period 10.55 days, larval feeding period 22.18 days, cocooning period 5.40 days, pupal period 11.03 days, life cycle 49.18 days, complete life cycle 51.25 days.

TABLE XVIII.—*Life cycle of the first generation of the codling moth, as observed by rearing, stock-jar feeding method, Grand Junction, Colo., 1915.*

Date of egg deposition.	Number of individuals.	Incubation.	Larval feeding period.			Cocooning period.			Pupal period.			Life cycle. ¹		
			Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
May	13	1	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
	23	4	14	27.00	27	27	4.00	4	4	12.00	12	12	57.00	57
	24	4	13	22.25	23	21	3.50	5	3	10.25	11	8	49.00	50
	24	11	13	21.45	25	19	5.36	11	2	10.81	13	6	50.63	54
	24	1	14	20.00	20	20	4.00	4	4	11.00	11	11	49.00	49
	26	2	13	20.00	21	19	5.00	8	2	9.00	10	8	47.00	48
	27	9	13	19.77	23	18	5.22	9	3	10.33	12	8	48.33	53
	29	11	12	20.63	22	18	5.09	7	3	11.27	13	10	49.00	51
	29	15	13	21.80	27	19	6.66	9	3	13.26	31	9	54.73	72
	31	3	12	20.66	22	19	14.33	28	4	10.66	12	9	57.66	70
June	1	2	12	20.50	21	20	7.00	7	7	10.00	11	9	49.50	51
	2	12	12	21.08	25	18	9.25	23	3	11.33	13	7	53.66	66
	4	31	11	19.83	27	14	6.77	20	3	11.45	20	7	49.06	65
	6	15	10	22.20	32	18	8.40	14	4	13.13	21	9	53.73	63
	9	20	8	20.55	26	15	7.55	14	2	11.60	14	8	47.70	56
	10	23	8	20.86	29	17	7.17	13	4	11.47	15	9	47.52	56
	11	13	8	20.84	26	19	6.84	13	3	12.38	25	10	48.07	57
	12	10	8	21.20	24	18	7.60	11	4	12.10	16	10	48.90	53
	13	6	8	21.00	24	19	6.66	9	4	12.50	14	11	48.16	52
	15	3	7	24.66	29	20	10.33	11	9	9.66	11	8	51.66	55
	16	3	7	22.66	25	20	6.66	10	2	12.00	14	10	48.33	50
	16	1	8	18.00	18	18	5.00	5	5	13.00	13	13	44.00	44
	18	1	7	21.00	21	21	12.00	12	12	11.00	11	11	51.00	51
	19	3	7	20.00	24	17	7.66	9	6	12.00	15	10	46.66	54
	20	2	7	18.50	20	17	5.00	6	4	11.00	12	10	41.50	45
	21	6	7	21.50	26	16	7.16	9	4	11.16	12	10	46.83	53
	21	4	8	17.50	19	15	6.50	8	5	11.00	12	10	43.00	46
	23	2	7	19.50	20	19	8.50	12	5	9.50	11	8	44.50	47
	25	1	7	16.00	16	16	5.00	5	5	11.00	11	11	39.00	39
	26	3	7	18.33	23	16	6.00	6	6	12.66	14	11	44.00	50
	27	2	7	17.50	18	17	6.00	6	6	12.00	12	12	42.50	43
	30	1	6	17.00	17	17	6.00	6	6	12.00	12	12	41.00	41
		221	9.91	20.75	32	14	6.99	28	2	11.64	31	6	49.30	72

¹ Add 2.07 days for complete life cycle.TABLE XIX.—*Life cycle of the first generation of the codling moth, as observed by rearing, bagged-fruit feeding method, Grand Junction, Colo., 1915.*

Date of egg deposition.	Number of individuals.	Incubation.	Larval feeding period.			Cocooning period.			Pupal period.			Life cycle. ¹		
			Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
May	16	1	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
	22	1	15	32.00	32	32	5.00	5	5	10.00	10	10	62.00	62
	22	1	11	25.00	25	25	4.00	4	4	10.00	10	10	50.00	50
	23	5	11	26.40	30	23	4.80	6	4	11.00	12	10	53.20	59
	23	8	12	27.37	32	23	6.25	15	3	10.62	13	9	56.25	63
	23	5	13	21.80	23	21	4.60	6	4	10.40	11	10	49.80	51
	24	8	13	21.12	22	21	4.12	5	3	10.75	13	9	49.00	52
	24	9	14	22.22	25	21	5.66	8	4	10.55	12	9	52.44	57
	26	3	13	26.33	27	26	7.33	12	4	9.00	11	8	55.66	60
	27	6	13	23.66	27	20	9.33	22	1	12.33	17	10	58.33	74
June	29	4	12	19.50	21	18	7.00	8	6	10.25	11	9	48.75	50
	29	2	13	19.00	20	18	5.00	5	5	11.50	12	11	48.50	50
	31	1	12	19.00	19	19	4.00	4	4	11.00	11	11	46.00	46
	1	5	12	21.20	26	19	4.80	6	4	10.80	12	9	48.80	55
	2	2	12	21.50	23	20	3.00	4	2	11.50	12	11	48.00	51
	4	3	11	20.33	21	20	4.66	5	4	11.00	12	10	47.00	48
	6	5	10	21.40	28	16	5.40	8	4	9.60	11	8	46.40	54
	9	4	8	20.50	21	19	4.25	5	3	11.50	13	10	44.25	46
	10	3	8	22.33	28	19	9.66	15	6	13.33	15	11	53.33	57
	13	8	8	23.25	29	21	4.75	7	4	12.75	19	11	48.75	53
	16	4	8	21.75	24	20	4.25	5	4	11.75	12	11	45.75	48
	18	1	7	21.00	21	21	5.00	5	5	12.00	12	12	45.00	45
	19	4	7	22.50	24	20	4.50	6	3	10.75	12	10	44.75	47
	21	3	7	17.00	19	15	4.33	5	4	10.66	11	10	39.00	41
	21	3	8	21.33	25	19	4.66	5	4	11.66	12	11	45.66	50
	23	3	7	18.00	20	16	4.00	5	3	10.00	11	9	39.00	41
	24	4	7	20.50	21	20	4.75	6	4	12.25	16	10	44.50	50
	25	4	7	18.75	21	18	6.50	10	3	10.00	13	8	42.25	44
		109	10.55	22.18	32	15	5.40	22	1	11.03	19	8	49.18	74

¹ Add 2.07 days for complete life cycle.

THE SECOND GENERATION.

EGGS OF THE SECOND BROOD.

Time of deposition.—Table XX shows the number of eggs deposited daily by moths of the first brood in oviposition jars in the insectary. It will be noted that the period of egg deposition extended from July 11 to September 15, inclusive, and that during this interval

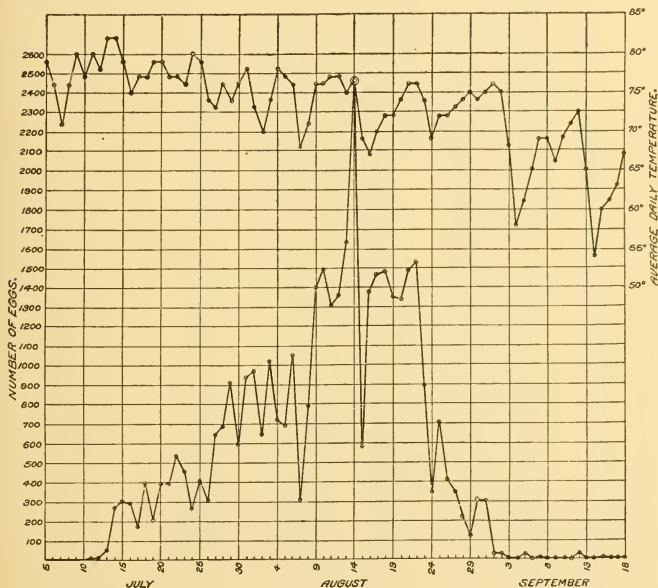


FIG. 8.—Time of deposition of eggs of the second brood of codling moth, Grand Junction, Colo., 1915.

38,485 eggs were deposited. The largest number deposited in any one day was 2,452 on August 14, as will be seen by reference to this table. The time of maximum deposition, as shown in figure 8, occurred about midway between the earliest and latest deposition.

TABLE XX.—*Time of deposition, length of incubation, and time of hatching of eggs of the second brood of the codling moth, Grand Junction, Colo., 1915.*

Observation No.	Number of eggs deposited.	Date—				Number of eggs hatched.	Appearance of—		Incubation period.
		De- posited.	Red ring.	Black spot.	Hatched.		Red ring.	Black spot.	
							Days.	Days.	Days.
1	6	July 11	July 13	July 17	July 19	0	2		7
2	10	July 12	do.	July 17	July 19	8	1	5	7
3	53	July 13	July 14	July 16	do.	50	1	3	6
4					July 20	2			7
5	271	July 14	July 15	July 19	do.	179	1	5	6
6					July 21	43			7
7	303	July 15	July 16	July 20	do.	170	1	5	6
8	288	July 16	July 17	July 21	July 22	282	1	5	6
9	176	July 17	July 18	do.	July 23	169	1	4	6
10	398	July 18	July 19	July 23	July 24	378	1	5	6
11					July 25	16			7
12	208	July 19	July 20	July 23	July 24	94	1	4	5
13					July 25	106			6
14	396	July 20	July 21	July 24	July 26	376	1	4	6
15					July 27	12			7
16	395	July 21	July 22	July 25	July 26	51	1	4	5
17					July 27	300			6
18	539	July 22	July 24	July 26	do.	32	2	4	5
19					July 28	496			6
20	455	July 23	July 25	July 28	July 29	446	2	5	6
21					July 30	5			7
22	261	July 24	July 25	July 28	do.	245	1	4	6
23					July 31	13			7
24	404	July 25	July 28	July 30	do.	315	3	5	6
25					Aug. 1	57			7
26	309	July 26	July 28	July 31	do.	250	2	5	6
27					Aug. 2	15			7
28	645	July 27	July 28	Aug. 1	do.	555	1	5	6
29					Aug. 3	58			7
30	684	July 28	July 31	Aug. 2	do.	588	3	5	6
31					Aug. 4	62			7
32	909	July 29	July 31	Aug. 3	do.	709	2	5	6
33					Aug. 5	64			7
34	595	July 30	Aug. 1	Aug. 4	do.	303	2	5	6
35					Aug. 6	256			7
36	937	July 31	Aug. 2	Aug. 5	do.	581	2	5	6
37					Aug. 7	311			7
38	966	Aug. 1	Aug. 3	Aug. 6	do.	58	2	5	6
39					Aug. 8	831			7
40	641	Aug. 2	Aug. 4	Aug. 7	do.	340	2	5	6
41					Aug. 9	244			7
42					Aug. 10	38			8
43	1,013	Aug. 3	Aug. 5	Aug. 8	Aug. 9	223	2	5	6
44					Aug. 10	760			7
45	720	Aug. 4	Aug. 6	Aug. 9	do.	554	2	5	6
46					Aug. 11	137			7
47	693	Aug. 5	Aug. 6	Aug. 10	do.	464	1	5	6
48					Aug. 12	194			7
49	1,045	Aug. 6	Aug. 8	Aug. 11	do.	543	2	5	6
50					Aug. 13	408			7
51	314	Aug. 7	Aug. 10	Aug. 12	do.	223	3	5	6
52					Aug. 14	69			7
53	787	Aug. 8	Aug. 10	Aug. 13	do.	401	2	5	6
54					Aug. 15	299			7
55	1,400	Aug. 9	Aug. 10	Aug. 14	do.	1,064	1	5	6
56					Aug. 16	224			7
57	1,495	Aug. 10	Aug. 11	Aug. 15	do.	837	1	5	6
58					Aug. 17	493			7
59					Aug. 18	75			8
60	1,311	Aug. 11	Aug. 12	Aug. 16	Aug. 17	105	1	5	6
61					Aug. 18	1,091			7
62					Aug. 19	66			8
63	1,358	Aug. 12	Aug. 13	Aug. 17	Aug. 18	81	1	5	6
64					Aug. 19	1,127			7
65					Aug. 20	95			8
66	1,626	Aug. 13	Aug. 14	Aug. 19	do.	1,480	1	6	7
67	2,452	Aug. 14	Aug. 16	Aug. 20	Aug. 21	2,280	2	6	7
68	583	Aug. 15	Aug. 17	Aug. 21	Aug. 22	501	2	6	7
69					Aug. 23	52			8
70	1,378	Aug. 16	Aug. 18	Aug. 21	Aug. 22	978	2	5	6
71					Aug. 23	269			7
72	1,462	Aug. 17	Aug. 20	Aug. 22	do.	1,067	3	5	6
73					Aug. 24	360			7
74	1,485	Aug. 18	Aug. 20	Aug. 23	do.	1,292	2	5	6
75					Aug. 25	163			7

TABLE XX.—*Time of deposition, length of incubation, and time of hatching of eggs of the second brood of the codling moth, Grand Junction, Colo., 1915—Continued.*

Observation No.	Number of eggs deposited.	Date—				Number of eggs hatched.	Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.		Red ring.	Black spot.	
							<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
76	1,353	Aug. 19	Aug. 21	Aug. 24	Aug. 25	352	2	5	6
77					Aug. 26	947			7
78	1,340	Aug. 20	Aug. 22	Aug. 25	do.	456	2	5	6
79					Aug. 27	616			7
80	1,490	Aug. 21	Aug. 24	Aug. 26	do.	45	3	5	6
81					Aug. 28	1,341			7
82	1,526	Aug. 22	Aug. 24	Aug. 27	do.	889	2	5	6
83					Aug. 29	504			7
84	895	Aug. 23	Aug. 26	Aug. 29	Aug. 30	841	3	6	7
85	343	Aug. 24	do.	Aug. 30	Aug. 31	278	2	6	7
86					Sept. 1	38			8
87	702	Aug. 25	Aug. 27	Aug. 30	Aug. 31	407	2	5	6
88					Sept. 1	288			7
89	412	Aug. 26	Aug. 28	Sept. 1	Sept. 2	325	2	6	7
90					Sept. 3	21			8
91	348	Aug. 27	Aug. 28	Sept. 1	do.	282	1	5	7
92					Sept. 5	28			9
93	224	Aug. 28	Aug. 29	Sept. 2	Sept. 3	146	1	5	6
94					Sept. 4	11			7
95					Sept. 5	45			8
96	129	Aug. 29	Aug. 31	Sept. 4	do.	18	2	6	7
97					Sept. 6	59			8
98					Sept. 7	31			9
99	309	Aug. 30	Sept. 1	Sept. 6	do.	133	2	7	8
100					Sept. 8	154			9
101					Sept. 9	19			10
102	300	Aug. 31	Sept. 1	Sept. 7	Sept. 8	171	1	7	8
103					Sept. 9	93			9
104					Sept. 10	21			10
105	35	Sept. 1	Sept. 3	Sept. 8	do.	30	2	7	9
106					Sept. 11	4			10
107	29	Sept. 2	Sept. 6	Sept. 10	do.	22	4	8	9
108					Sept. 12	6			10
109	28	Sept. 5	Sept. 8	Sept. 13	Sept. 14	22	3	8	9
110					Sept. 15	1			10
111					Sept. 16	1			11
112	4	Sept. 6	Sept. 8	Sept. 14	Sept. 15	3	2	8	9
113					Sept. 16	1			10
114	7	Sept. 7	Sept. 9	Sept. 15	do.	1	2	8	9
115					Sept. 17	1			10
116	2	Sept. 8	Sept. 11	Sept. 17	Sept. 18	2	3	9	10
117	3	Sept. 9	do.	do.	Sept. 19	2	2	8	10
118					Sept. 20	1			11
119	2	Sept. 10	Sept. 12	Sept. 18	do.	2	2	8	10
120	32	Sept. 12	Sept. 14	Sept. 20	Sept. 22	26	2	8	10
121	1	Sept. 15	Sept. 18	Sept. 23	Sept. 24	1	3	8	9
Total.	38,485					35,804			
Av.							1.85	5.54	7.22
Max.							4	8	11
Min.							1	3	6

Length of incubation.—A record of the observations of the embryological development and incubation period of the eggs of the second brood will be found in Table XX. It will be observed that the length of the incubation period was increased toward the latter part of the season, as the temperatures became lower. The average number of days from the time of deposition to the appearance of the red ring was 1.85, maximum 4 days, and minimum 1 day; the average number of days from the time of deposition to the appearance of the

black spot was 5.54 days, maximum 8 days, and minimum 3 days; the average length of the incubation period was 7.22 days, maximum 11 days, and minimum 6 days.

LARVÆ OF THE SECOND BROOD.

Time of hatching.—By reference to Table XX it will be seen that the time of hatching of eggs of the second brood extended over a period of more than two months, namely, from July 19 to September 24. The largest number hatching in any one day was 2,280 on August 21, a date which is just midway between that when the first

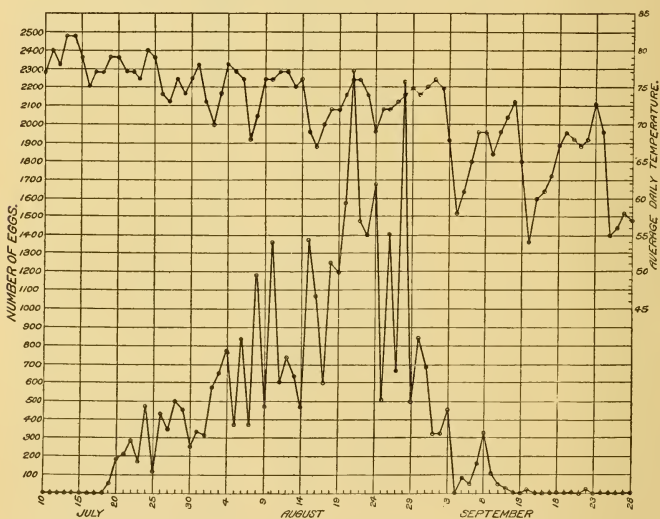


FIG. 9.—Time of hatching of eggs of the second brood of the codling moth, Grand Junction, Colo., 1915.

larvæ of this brood appeared and the date when the last larva hatched. In figure 9 the daily hatching record is shown diagrammatically with average daily temperatures.

Length of the feeding period.—The length of the feeding period of larvæ of the second brood was established by means of the stock-jar method (see p. 8). The observations of 1,939 larvæ are presented in Table XXI, in which it will be noted that the feeding periods during the warmer weather of July and August were considerably shorter than those during September and October. The first larvæ of the second brood entered the fruit July 19, and although some of

the larvæ hatched and commenced feeding as late as September 24, none that entered the fruit later than September 12 successfully completed its feeding period. The average length of the feeding period was 28.69 days, the maximum 67 days, and the minimum 15 days.

TABLE XXI.—Length of feeding period of larvæ of the second brood of the codling moth, stock-jar method, Grand Junction, Colo., 1915.

Date of entering fruit.	Number of individuals.	Length of feeding period in specified days.																																					
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38														
July	19	20			3	1	2	2			3	2		2	2	1	1																						
	20	43		1	1	1	2	5		7	4	4	4	3	3	2	3	2	1																				
	21	81		1	5		2	10	12	5	5	7	5	4	3	2	5	2	3		3		5																
	22	74				2	7	6	8	5	13	8	4	3	7	2	3	5	4		1																		
	23	28					2	1		3			1	1	3	1	3	2	1		2		1																
	24	67			1	1	6			15	10		9	6		2	2	2	3	5																			
	25	20				2		2		3	2	5		2	1	1			2	1																			
	26	48					2	6			5	7	2	11	3	1	2		4																				
	27	34				1	2	2	2	9	2	5	3	2	2	2	1	3	2	2	1	3	2																
	28	38			2			1	4	5	6	3		7	4					1	1																		
29	50				2		5	7	4	6	6	6	3	2	4	3	1			5		2																	
30	39					1	3	4	4	3	5	7	4	2	1	1		1			1																		
31	58					4	11	10	5	6	5	3	5	1	1	2	3																						
Aug.	1	1																																					
	2	62		1																																			
	3	52																																					
	4	37					1	1	1	11	2	4	4	3	3	2	3	3	2	2	2	1	1																
	5	56						2		5	3	1	7	4	7	7	5	2	2	2	1	2	4	3															
	6	64							2	4	1	12	6	7																									
	7	51		1					3	7	13	6	16	9	2	4	5	2	1	2	2	2	2	1	1														
	8	81										13	6	16	9	2	4	5	2	1	2	2	2	2	1	1													
	9	55							1	11	7	8	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2					
	10	57			3	1	3	2	3	6	8	3	7	8	3	2	2	5	1	2	4	1	1	3	4	1													
11	28			1			2	2	3	3	1	2	1	2		3	2	2	3	3	2	3																	
12	47				3	4	4	6	3	2	1	2	1	2	1	6	4	4		5	1																		
13	49																																						
14	38				1		2	1	2	3	6	6	3	1	3	3	6	2		4	1																		
15	35			1						2		4	4	3	2	1	2		2																				
16	44						1				1	8	4	6	2	6		1																					
17	29					1			1	4				2	5	2	2	5		1																			
18	40										2	3	7	1			2	3	2	1	3	3	2	2	2	2	2	2	2	2	2	3							
19	39									1	1	10		1	1	2	4	6		4	2	2	1	3	5	1	1	1	1	1	1	1							
20	34										1	5	4	1	1					4	2	2	1	3	2	1													
21	41													3	10	9	5			4	2	1	3																
22	2																																						
23	22										1	1	1			3	1	1	6	2	2	6																	
24	21								1			1	1			2	2	1	2	2	1	2																	
25	27											1	1	1		1	4	4	1	1	2																		
26	40															4	2	1	3	3	2		6																
27	29															3	2	4	1	1	3	2																	
28	21															2	3			3	1		3	1															
29	32															3				3	3																		
30	24															1	1	2			1	2																	
31	21															1		1	2		1	2																	
Sept.	1	17																																					
			1	4	13	19	57	93	132	144	142	167	135	123	99	105	89	69	47	62	40	56	35	15	19	25													

TABLE XXI.—Length of feeding period of larvæ of the second brood of the codling moth, stock-jar method, Grand Junction, Colo., 1915—Continued.

Date of entering fruit.		Number of individuals.	Length of feeding period in specified days.																												
			39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
July	24	67	2																												
	28	38		1																											
Aug.	1	52	1	1																											
	2	62	1																												
	5	56										1																			
	6	64	2		1				1				1																		
	7	51	1		1		1	1		1																					
	8	81		1	1	1				1		1																			
	9	55											2																		
	10	57				1	1								3																
	11	28	2	1																											
	12	47		1																											
	13	49	2	1			1		1	1																					
	14	38	1	1																											
	15	35		3				1	1																						
	16	44		1					2	1																					
	17	29	1				1			1	2																				
	18	40		1	1			3																							
	19	39	1			1	2																								
	20	34	2	1	1																										
	21	41	1							1																					
	24	21	2	1	1								1																		
	25	27	1				2												1												
	26	40		1	1			2	1	1	1	4	1							2			1								
	27	29	3		1	1		1	1			3		1					1		2									1	
	28	21		1					2										1	2											
	29	32	4			1	1												4									1			
	30	24	1	2			3					3											2								
Sept.	31	21		2	2			1		1			1							1	2										
	1	17		1	3							1		3	1		2			1						1					
	2	12			1					1		1	1		1	1								1	2		1			1	
	3	16		2	1			2		1	1	1	1		1								3		1	2	1				
	4	12	2				1					1										2	3								
	5	8								1	1		1						1								1		1		
	6	10					1				1						1	1				1			3				1		
	7	8								1									1	1											
	8	3										1	2	1		1						1									
	9	9							1									2	1	1	1							1			
	10	3														1							2								
	12	1																1													
		1,939	29	22	16	15	12	12	12	6	17	7	6	5	6	8	7	4	11	8	4	10	7	4	5	3	4	3	2	1	2

Days.

Average length of feeding period..... 28.69
 Maximum length of feeding period..... 67
 Minimum length of feeding period..... 15

Length of the cocooning period.—The time consumed in constructing the cocoon by the transforming larvæ of the second brood will be found in Table XXII. As will be noted therein, the average cocooning period for 20 individuals was 9.35 days, the maximum 31 days, and the minimum 3 days. The maximum here reported is the longest cocooning period secured for any larva throughout this and the following season. As will be seen from Table XXII, this individual left the fruit September 1 and pupated October 2.

TABLE XXII.—Length of cocooning period of transforming larvæ of the second brood of the codling moth, Grand Junction, Colo., 1915.

Larvæ left fruit.	Number of individuals.	Length of cocooning period in specified days, being the time from leaving the fruit to the time of pupation.											Average.	Maximum.	Minimum.
		3	4	5	6	7	8	10	11	12	16	31			
Aug. 5	2	.....	.....	.....	.....	.....	.....	1	.....	1	.....	.....	Days.	Days.	Days.
7	1	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	11.00	12	10
8	1	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.00	12	12
9	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	4.00	4	4
10	1	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	5.00	5	5
11	1	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	6.00	6	6
12	1	.....	1	.....	.....	.....	.....	1	.....	.....	.....	.....	10.00	10	10
13	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	3.00	3	3
16	2	.....	.....	.....	1	1	.....	.....	.....	.....	.....	.....	16.00	16	16
19	1	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	6.50	7	6
20	3	.....	.....	.....	.....	1	1	1	.....	.....	.....	.....	6.00	6	6
22	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	8.33	10	7
28	1	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	5.00	5	5
Sept. 1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	12.00	12	12
3	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	31.00	31	31
7	1	.....	.....	.....	1	.....	.....	.....	1	.....	.....	.....	11.00	11	11
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.00	6	6
Total.	20	1	1	2	4	2	1	3	1	3	1	1	9.35	31	3

PUPE OF THE SECOND BROOD.

Time of pupation.—It will be observed in Table XXIII and figure 10 that pupation of the second brood occurred from August 12 to October 2, inclusive.

Length of the pupal stage.—In Table XXIV the length of the pupal stage of 16 pupæ of the second brood is given

and, as recorded therein, the average was 15.62 days, the maximum 31 days, and the minimum 11 days.

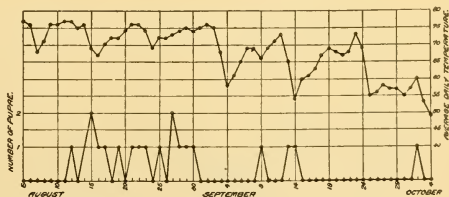


FIG. 10.—Time of pupation of the second brood of the codling moth, Grand Junction, Colo., 1915.

TABLE XXIII.—Time of pupation of transforming larvæ of the second brood of the codling moth, Grand Junction, Colo., 1915.

Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.
Aug. 12	1	Aug. 19	1	Aug. 27	2	Sept. 13	1
14	1	21	1	28	1	14	1
15	2	22	1	29	1	Oct. 2	1
16	1	23	1	30	1		
17	1	25	1	Sept. 9	1	Total.	20

TABLE XXIV.—*Length of the pupal stage of pupæ of the second brood of the codling moth, Grand Junction, Colo., 1915.*

Date of pupation.	Number of individuals.	Length of the pupal stage in specified days.							
		11	12	13	14	16	19	21	31
Aug. 12	1	1	.....	.....	.....	.....	.....	.....	.....
14	1	1	.....	.....	.....	.....	.....	.....	.....
15	1	.....	.....	.....	1	.....	.....	.....	.....
17	1	.....	1	.....	.....	.....	.....	.....	.....
19	1	.....	.....	1	.....	.....	.....	.....	.....
22	1	.....	.....	.....	.....	1	.....	.....	.....
23	1	.....	.....	.....	1	.....	.....	.....	.....
25	1	.....	.....	1	.....	.....	.....	.....	.....
27	2	.....	.....	.....	2	.....	.....	.....	.....
28	1	.....	.....	.....	.....	.....	.....	1	.....
29	1	.....	.....	.....	1	.....	.....	.....	.....
30	1	.....	.....	.....	.....	.....	1	.....	.....
Sept. 9	1	.....	.....	.....	1	.....	.....	.....	.....
13	1	.....	.....	.....	.....	.....	.....	.....	1
11	1	.....	.....	.....	.....	.....	1	.....	.....
	16	2	1	2	6	1	2	1	1

	<i>Days.</i>
Average length of pupal stage	15.62
Maximum length of pupal stage	31
Minimum length of pupal stage	11

MOTHS OF THE SECOND BROOD.

Time of emergence.—The time of emergence of moths of the second brood reared from insectary-bred material is presented in Table

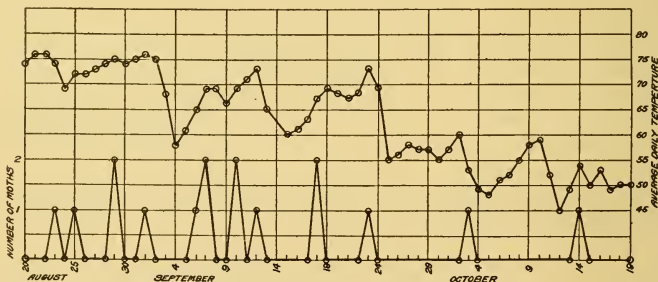


FIG. 11.—Time of emergence of moths of the second brood of the codling moth, Grand Junction, Colo., 1915.

XXV and figure 11. The first moth of this brood issued August 23, the last October 14; thus the emergence extended over a period of more than one and a half months.

TABLE XXV.—*Time of emergence of codling moths of the second brood, Grand Junction, Colo., 1915.*

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
Aug. 23	1	Sept. 12	1
25	1	18	2
29	2	23	1
Sept. 1	1	Oct. 3	1
6	1	14	1
7	2	Total...	16
10	2		

LIFE CYCLE OF THE SECOND GENERATION.

In Table XXVI are given the summarized data showing the average length of each period in the life cycle of the codling moth as derived from observations of 16 individuals of the second generation reared by the stock-jar feeding method. It will be noted that the average length of the incubation period was 6.12 days, the larval feeding period 20.49 days, the cocooning period 8.56 days, the pupal period 15.62 days, and the average life cycle 50.81 days.

TABLE XXVI.—*Life cycle of the second generation of the codling moth, as observed by rearing by the stock-jar feeding method, Grand Junction, Colo., 1915.*

Date of egg deposition.	Number of individuals.	Incubation.	Larval feeding period.			Cocooning period.			Pupal period.			Life cycle.		
			Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
		<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
July 13	2	6	18.50	20	17	8.00	12	4	11.50	12	11	44.00	47	41
14	3	6	19.33	24	16	12.66	16	10	13.66	14	13	51.66	60	46
16	2	6	21.50	25	18	5.50	6	5	13.50	16	11	46.50	53	40
21	1	6	20.00	20	20	7.00	7	7	14.00	14	14	47.00	47	47
25	4	6	19.75	20	19	7.75	10	6	16.75	21	13	50.25	55	44
27	1	6	20.00	20	20	5.00	5	5	14.00	14	14	45.00	45	45
31	1	6	28.00	28	28	11.00	11	11	19.00	19	19	64.00	64	64
Aug. 3	1	7	18.00	18	18	12.00	12	12	14.00	14	14	51.00	51	51
6	1	7	25.00	25	25	6.00	6	6	31.00	31	31	69.00	69	69
	16	6.12	20.49	28	16	8.56	16	4	15.62	31	11	50.81	69	40

THE THIRD GENERATION.

Owing to the small number of moths of the second brood that were reared at the insectary, data of the third generation were not secured. The moths of the second brood deposited third-brood eggs but none of these hatched. Complete data of the third generation, however, were obtained in 1916 (see p. 75-78).

CODLING-MOTH BAND STUDIES OF 1915.

Two orchards were selected for banding purposes. The first of these, known as the Edwards orchard, was unsprayed; it was located about one-half mile west of the insectary. The second, or Hamilton

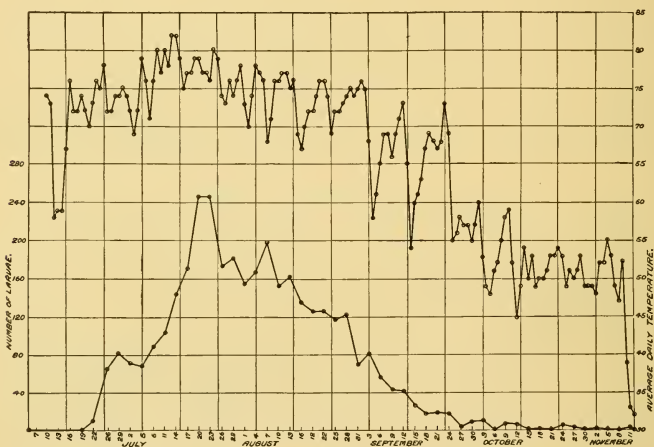


FIG. 12.—Number of larvæ of the codling moth collected from banded trees, Edwards orchard, Grand Junction, Colo., 1915.

orchard, was well sprayed throughout the season, and was located about 2 miles west and $3\frac{1}{2}$ miles north of the insectary. Certain trees in each orchard were scraped to remove the loose bark on the trunk and larger limbs and were then banded with a strip of burlap cloth, folded to three thicknesses, having a width after folding of about 5 inches. These bands were removed every three days with one exception in both orchards when the interval was four days. The larvæ of each collection were kept separate and were allowed to spin up in corrugated pasteboard strips at the insectary for further study.

In Table XXVII and figure 12 will be found the data for the Edwards orchard. As noted therein, the first larval collection was made June 22 and the last November 11, and during this period 3,551 larvæ were secured. The maximum number of larvæ collected at any one time was 250, and this number was successively obtained on July 20 and 23. During the season of 1915, 1,417 moths, or 39.96

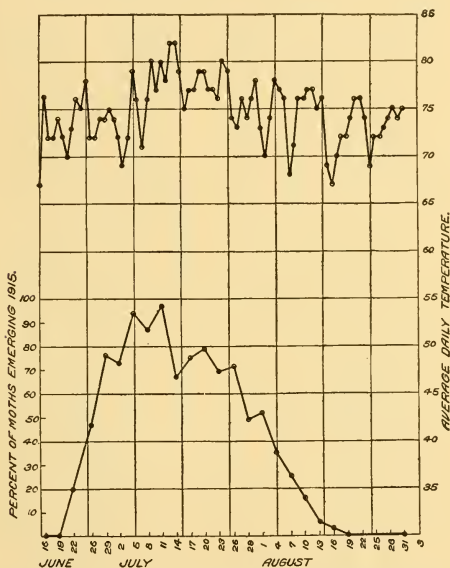


FIG. 13.—Percentage of codling moths emerging from band-collected material, Edwards orchard, Grand Junction, Colo., 1915.

per cent. of the total number of larvæ collected, issued from the band material. The percentage of moths emerging from each collection is shown in figure 13. No moths from this orchard emerged in 1915 from larvæ collected after August 16. In the following spring 976, or 27.52 per cent, of the moths emerged. The remainder of the larvæ, 32.52 per cent, failed to transform to the adult stage.

TABLE XXVII.—*Band-record experiment. Codling moth larvæ collected at the Edwards orchard, Grand Junction, Colo., 1915.*

Date of collection, 1915.	Collection No.	Number of larvæ collected.	Total number of moths emerging, 1915.	Total number of moths emerging, 1916.	Per cent of—		
					Moths emerging, 1915.	Moths emerging, 1916.	Dead individuals.
June 22	1	10	2	0	20.00	0	80.00
26	2	66	31	0	46.96	0	53.04
29	3	82	62	0	75.60	0	24.40
July 2	4	¹ 72	51	0	¹ 72.80	0	¹ 27.15
5	5	² 69	63	0	² 94.02	0	² 5.98
8	6	89	77	0	86.51	0	13.49
11	7	³ 104	100	1	³ 97.08	⁴ 0.97	⁴ 1.95
14	8	144	97	0	67.36	0	32.64
17	9	171	123	1	74.85	0.58	24.57
20	10	250	197	3	78.80	1.20	20.00
23	11	250	173	9	69.20	3.60	27.20
26	12	173	123	10	71.09	5.78	23.13
29	13	182	89	17	48.90	9.34	41.76
Aug. 1	14	155	80	37	51.61	23.87	24.52
4	15	167	58	55	34.73	32.94	32.33
7	16	198	49	85	24.74	42.97	32.29
10	17	153	24	43	15.68	28.10	56.22
13	18	162	9	50	5.55	30.86	63.59
16	19	135	4	100	2.96	74.07	22.97
19	20	126	0	63	0	50.00	50.00
22	21	127	0	78	0	61.41	38.59
25	22	117	0	88	0	75.21	24.79
28	23	123	0	81	0	65.85	34.15
31	24	70	0	44	0	62.85	37.15
Sept. 3	25	82	0	54	0	65.85	34.15
6	26	56	0	40	0	71.42	28.58
9	27	44	0	34	0	27.27	22.73
12	28	42	0	13	0	30.95	69.05
15	29	27	0	15	0	55.55	44.45
18	30	18	0	11	0	61.11	38.89
21	31	19	0	13	0	68.42	31.58
24	32	18	0	8	0	44.44	55.56
27	33	4	0	1	0	25.00	75.00
30	34	9	0	2	0	22.22	77.78
Oct. 3	35	10	0	7	0	70.00	30.00
6	36	0	0	0	0	0	0
9	37	7	0	4	0	57.14	42.86
12	38	6	0	1	0	16.66	83.34
15	39	1	0	1	0	100.00	0
18	40	1	0	1	0	100.00	0
21	41	0	0	0	0	0	0
24	42	5	0	1	0	20.00	80.00
27	43	3	0	3	0	1.00	0
30	44	0	0	0	0	0	0
Nov. 2	45	2	0	1	0	50.00	50.00
5	46	0	0	0	0	0	0
8	47	0	0	0	0	0	0
11	48	2	0	1	0	50.00	50.00
Total larvæ...		3,551					
Total moths...		1,417		976	¹ 39.96	² 27.52	³ 32.52

¹ A larva killed in handling; 1 killed by predatory spider.² 2 larvæ killed in handling.³ 1 larva killed in handling.⁴ All percentages based upon number of live larvæ collected.

The data in connection with the band studies made at the Hamilton orchard are shown in Table XXVIII and figure 14. The earliest collection was made June 28; the latest, October 21 following the final harvest of the fruit. A total of 4,183 larvæ was collected from which 2,092 moths, or 50.01 per cent, emerged in 1915. No moths issued during the season of 1915 from any larvæ that were collected in this orchard after August 19. For the percentage of moths issuing in 1915 from each collection of larvæ see figure 15. In the

spring of 1916, 869 moths issued, or 20.77 per cent of the total number of larvæ collected. The rest of the material, 29.22 per cent, did not reach the adult stage.

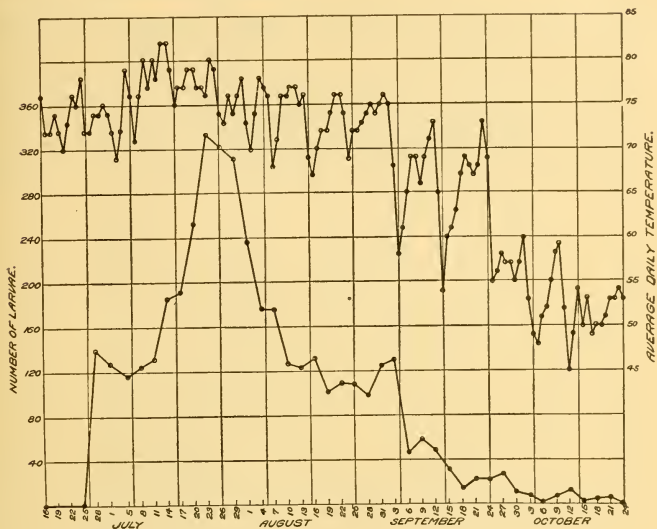


FIG. 14.—Number of larvæ of codling moth collected from banded trees, Hamilton orchard, Grand Junction, Colo., 1915.

Under field, or normal, conditions, there is a distinct overlapping of the larvæ of the first and second broods and of the second and third broods and similarly the moths of the first and second broods overlap. Hence with larvæ collected in the field it is impossible to know at all times to which brood the individuals belong. But with the insects reared at the insectary the brood identity

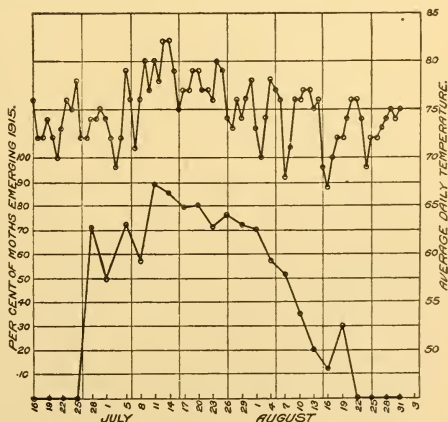


FIG. 15.—Percentage of codling moths emerging from band-collected material, Hamilton orchard, Grand Junction, Colo., 1915.

of each individual is definitely known, and this information aids in the establishment of the approximate limits of the broods as they occur in the field.

TABLE XXVIII.—*Band-record experiment. Codling moth larvæ collected at the Hamilton orchard, Grand Junction, Colo., 1915.*

Date of collection, 1915.	Collection No.	Number of larvæ collected.	Total number of moths emerging, 1915.	Total number of moths emerging, 1916.	Per cent of—		
					Moths emerging, 1915.	Moths emerging, 1916.	Dead individuals.
June 28	1	138	98	0	71.01	0	28.99
July 1	2	127	63	0	49.60	0	50.40
5	3	116	84	0	72.41	0	27.59
8	4	124	71	0	57.25	0	42.75
11	5	130	116	0	89.23	0	10.77
14	6	185	158	2	85.40	1.08	13.52
17	7	191	151	1	79.05	5.23	15.72
20	8	252	201	3	79.76	1.19	19.05
23	9	333	238	8	71.47	2.40	26.13
26	10	322	245	8	76.08	2.48	21.44
29	11	311	225	14	72.34	4.50	23.16
Aug. 1	12	235	165	13	70.21	5.53	24.26
4	13	176	101	25	57.38	14.20	28.42
7	14	176	89	53	50.56	30.11	19.33
10	15	127	44	31	34.64	24.40	40.96
13	16	123	24	37	19.51	30.08	50.41
16	17	131	16	51	12.21	38.93	48.86
19	18	101	3	54	29.70	53.46	16.84
22	19	109	0	54	0	49.54	50.46
25	20	108	0	82	0	75.92	24.08
28	21	98	0	81	0	82.65	17.35
31	22	123	0	76	0	61.78	38.22
Sept. 3	23	129	0	100	0	77.51	22.49
6	24	46	0	26	0	56.52	43.48
9	25	58	0	30	0	51.72	48.28
12	26	48	0	22	0	45.83	54.17
15	27	31	0	16	0	51.16	48.89
18	28	14	0	11	0	78.57	21.43
21	29	23	0	15	0	65.21	34.79
24	30	22	0	13	0	59.09	40.91
27	31	27	0	18	0	66.66	33.34
30	32	11	0	8	0	72.72	27.28
Oct. 3	33	8	0	4	0	50.00	50.00
6	34	1	0	0	0	0	100.00
9	35	6	0	2	0	33.33	66.67
12	36	12	0	7	0	58.33	41.67
15	37	2	0	1	0	50.00	50.00
18	38	4	0	2	0	50.00	50.00
21	39	5	0	1	0	20.00	80.00
Total larvæ...		4,183					
Total moths...			2,092	869	50.01	20.77	29.22

In figure 16 is presented the total combined number of moths emerging daily from the larvæ collected in the Edwards and Hamilton orchards during the season of 1915. As will be observed therein, the moths began to emerge on July 9 and continued their emergence until September 8, except on September 4 and 6, when no moths issued. The maximum emergence, 152 moths, issued August 6. The total number of moths emerging from this combined material in 1915 was 3,509 and in the spring of 1916, 1,845, or 45.37 per cent and 23.86 per cent, respectively, of the total number of larvæ collected. The rest of the larvæ, 2380, or 30.77 per cent, died over winter or through injury as a result of handling or from other undetermined causes.

The life-history data obtained in 1915 are shown in diagram in figure 17.

SEASONAL-HISTORY STUDIES OF 1916.

During the season of 1916 the life-history studies of the codling moth were continued along the same lines as in the preceding year. In several instances, however, the work was elaborated somewhat, since the amount of material on hand was a little larger than in 1915. The biology of the codling moth in 1916 was quite similar to that of 1915, except that the second generation began somewhat earlier in the season. Full data on the third brood were obtained.

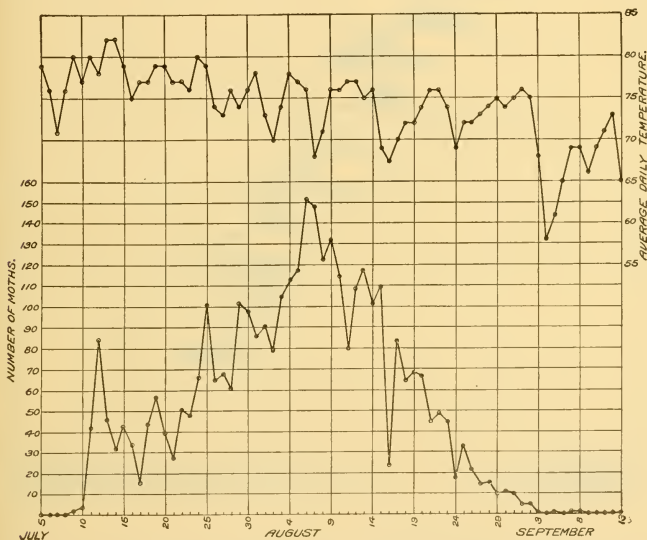


FIG. 16.—Time of emergence of codling moths from band-collected material, Hamilton and Edwards orchards, Grand Junction, Colo., 1915.

The blooming period of apple trees occurred in 1916 about the same time as in the previous year and, as in 1915, was followed by a little freezing weather. On the morning of June 30 the temperature dropped to 27° or 28° F. in some parts of the valley, while on the next morning the temperature was about 1° lower. At this time about 85 to 90 per cent of the blossoms had dropped in the orchards of the Fruitvale district. While some injury resulted from these freezes, it was not sufficient to cause a serious crop loss. Frost rings and pits, the latter being in the calyx cavity, developed in much of the fruit, however, and, as a result, the codling moth larvæ frequently entered the fruit through these frost pits.

PUPÆ OF THE SPRING BROOD.

Time of pupation.—The daily observations of the time of pupation of the wintering larvæ are tabulated in Table XXIX and pre-

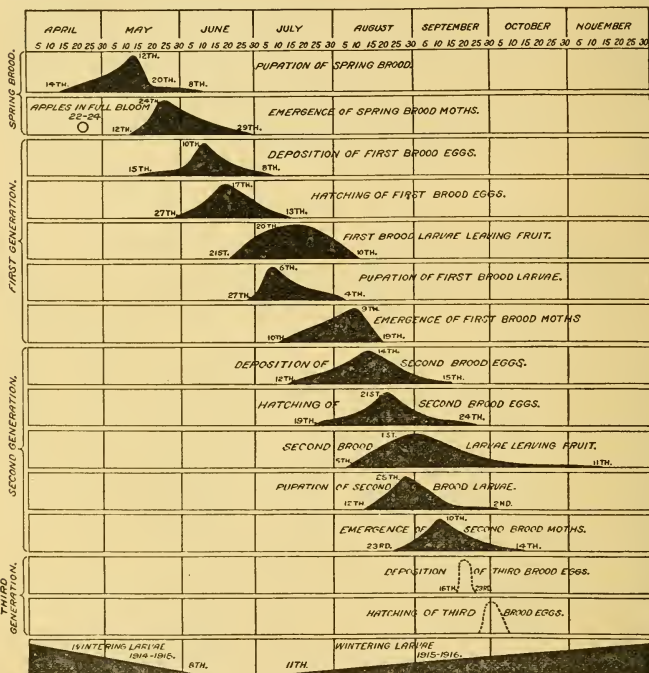


FIG. 17.—Diagram of life history of the codling moth in the Grand Valley of Colorado, 1915. sented graphically in figure 18. Reference to this table will show that 508 larvæ were under observation and that the earliest pupation

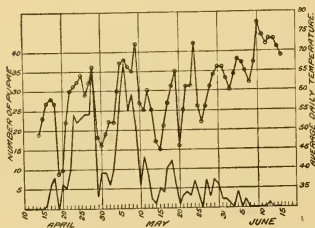


FIG. 18.—Time of pupation of spring brood of the codling moth, Grand Junction, Colo., 1916.

occurred April 16 and the latest June 12, the period thus covering about two months. The maximum pupation took place May 6, when 37 individuals pupated. On April 28, 36 larvæ transformed to pupæ, and if weather conditions had continued normal for the remainder of the month, it is probable that the maximum pupation would have occurred about May 1; but, as will be seen in the graph, the

TABLE XXX.—Length of the pupal stage of pupæ of the spring brood of the codling moth, Grand Junction, Colo., 1916—Continued.

Date of pupa- tion.	Num- ber of indi- vid- uals.	Length of the pupal stage in specified days.																													
		13	14	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	34	36									
May	15	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	16	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	17	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	18	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	19	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	20	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	21	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	22	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	23	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	24	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	25	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	27	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	28	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
June	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	4	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	12	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pupæ....	390	1	2	3	11	10	2	3	6	6	12	9	8	37	80	77	58	40	18	4	2	1									

Days.

Average length of pupal stage..... 26.8
 Maximum length of pupal stage..... 36
 Minimum length of pupal stage..... 13

MOTHS OF THE SPRING BROOD.

Time of emergence.—The tabulated data of the time of emergence of 4,808 moths of the spring brood are given in Table XXXI. The first of these emerged May 10 and the emergence period continued until June 28, when the last moth of this brood issued. The emergence reached its maximum on May 24, on which day 552 moths appeared. On the preceding day, May 23, the next highest in number, 432 moths, issued. The retardation of emergence, as caused by adverse climatic factors on May 20, is readily seen by the marked decrease in emergence from 309 moths May 19 to 3 moths May 20. The daily rate of emergence is shown in figure 19.

TABLE XXXI.—Time of emergence of codling moths of the spring brood, Grand Junction, Colo., 1916.

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
May 10	3	May 21	13	June 1	169	June 11	74	June 21	1
11	10	22	368	2	80	12	58	22	5
12	21	23	432	3	146	13	42	23	1
13	49	24	552	4	150	14	43	24	3
14	8	25	151	5	120	15	29	25	2
15	4	26	135	6	97	16	26	26	1
16	39	27	160	7	45	17	17	27	0
17	36	28	274	8	86	18	17	28	1
18	162	29	247	9	79	19	11		
19	309	30	283	10	53	20	14	Total ...	4,808
20	3	31	179						

Oviposition by moths of the spring brood.—The data obtained from the oviposition studies of 1,449 female moths confined in 123 cages with 1,292 male moths are presented in Table XXXII. The summarized figures give for the average number of days from the time of emergence to day of first oviposition 6.07, maximum 13 days, minimum 2 days; average number of days of oviposition 13.38, maxi-

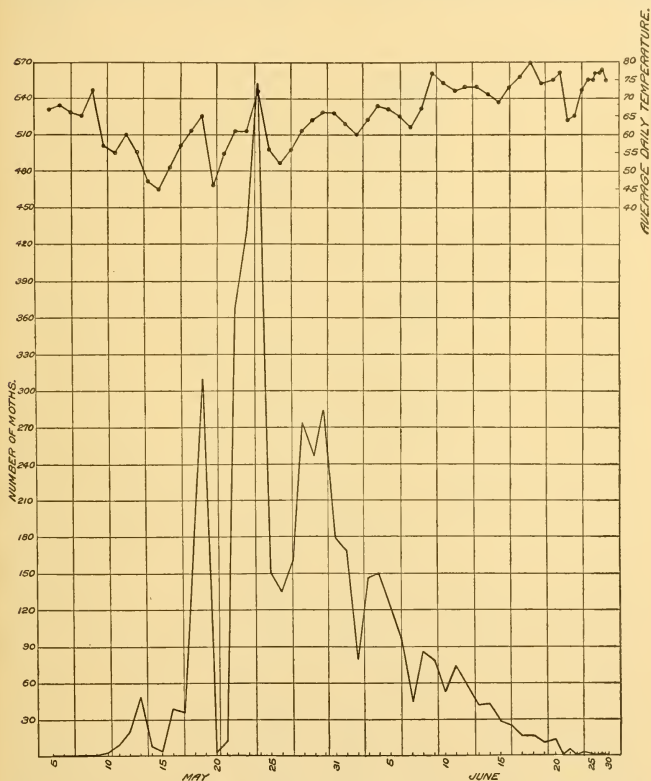


FIG. 19.—Time of emergence of codling moths of the spring brood, Grand Junction, Colo., 1916.

imum 32 days, minimum 1 day; average number of days from the date of emergence to last oviposition 18.46, maximum 34 days, minimum 7 days.

Number of eggs per female moth.—In connection with the oviposition studies of moths of the spring brood, it was found that the average number of eggs per female moth was 11.34.

TABLE XXXII.—*Oviposition by codling moths of the spring brood in rearing cages, Grand Junction, Colo., 1916.*

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male.	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition.	From date of emergence to last oviposition.
1	20	10	10	May 13	May 21	June 4	76	8	15	22
2	5	3	2	May 14			1			
3	13	7	6	May 16	May 19	June 4	89	3	17	19
4	23	14	9	May 17	May 22	June 1	110	5	14	18
5	25	19	6	do.	May 24	June 1	145	7	9	15
6	25	20	5	do.	do.	June 16	209	7	24	30
7	26	18	8	May 18	May 23	June 5	184	5	14	18
8	28	17	11	do.	do.	June 11	440	5	20	24
9	27	18	9	do.	May 24	do.	241	6	19	24
10	25	10	15	May 19	May 23	June 6	283	4	15	18
11	15	8	7	do.	do.	June 10	247	4	19	22
12	25	11	14	do.	May 24	June 8	267	5	16	20
13	23	12	11	do.	do.	June 14	304	5	22	26
14	24	13	11	do.	May 27	June 11	135	6	16	21
15	23	7	16	do.	do.	June 16	210	6	21	26
16	24	11	13	do.	May 31	June 13	286	12	14	25
17	1	1	1	May 20			0			
18	2	1	1	May 21			1			
19	22	11	11	May 22	May 26	June 11	229	4	17	20
20	25	8	17	do.	do.	June 16	202	4	22	25
21	21	13	8	do.	May 27	June 14	214	5	19	23
22	24	14	10	do.	do.	June 17	138	5	22	26
23	16	4	12	do.	May 28	June 14	186	6	18	23
24	25	10	15	do.	May 29	June 11	79	7	14	20
25	25	7	18	do.	do.	June 16	186	7	19	25
26	25	11	14	do.	May 30	June 9	86	8	11	18
27	24	11	13	May 23	May 26	June 12	189	3	18	20
28	26	14	12	do.	May 27	June 9	258	4	14	17
29	20	5	15	do.	do.	June 17	322	4	22	25
30	25	10	15	do.	May 29	June 11	198	6	14	19
31	23	12	11	do.	do.	do.	254	6	14	19
32	25	14	11	do.	do.	June 15	172	6	18	23
33	23	9	14	do.	do.	do.	244	6	18	23
34	25	14	11	do.	May 31	June 11	154	8	12	19
35	16	4	12	do.	June 3	June 17	44	11	15	25
36	24	11	13	May 24	May 29	June 12	179	5	15	19
37	25	8	17	do.	do.	June 5	11	6	7	12
38	25	11	14	do.	do.	June 8	40	6	10	15
39	24	7	17	do.	do.	June 12	45	6	14	19
40	20	13	7	do.	May 31	June 16	12	7	19	23
41	25	12	13	do.	do.	June 18	50	7	19	25
42	24	13	11	do.	June 1	June 15	156	8	15	22
43	24	11	13	do.	June 2	June 8	49	9	7	15
44	25	11	14	do.	June 3	June 17	63	10	15	24
45	25	12	13	do.	June 6	do.	108	13	12	24
46	25	9	16	do.	do.	June 6	1	13	1	13
47	20	14	6	do.			14			
48	13	6	7	do.			1			
49	25	11	14	May 25	June 4	June 17	247	10	14	23
50	24	11	13	do.	June 5	June 11	44	11	7	17
51	25	14	11	do.	do.	June 16	226	11	12	22
52	11	7	4	do.	June 7	June 13	78	13	7	19
53	23	12	11	May 26	May 31	June 20	182	5	21	25
54	25	12	13	do.	June 1	June 16	83	6	16	21
55	14	4	10	do.	June 3	June 17	68	8	15	22
56	24	10	14	do.	June 5	June 18	141	10	14	23
57	20	12	8	May 27	May 30	June 6	91	3	8	10
58	25	8	17	do.	June 3	June 16	63	7	14	20
59	25	12	13	do.	June 4	June 13	17	8	10	17
60	19	9	10	do.	June 8	do.	97	12	6	17
61	27	8	19	May 28	May 31	June 14	57	3	15	17
62	25	14	11	do.	do.	July 1	19	3	32	34
63	22	10	12	do.	June 1	June 9	126	4	9	12
64	24	8	16	do.	June 2	June 17	97	5	16	20
65	24	10	14	do.	June 3	June 25	241	6	23	28
66	27	11	16	do.	June 5	June 9	53	8	5	12
67	27	12	15	May 29	June 2	June 15	194	4	14	17
68	25	11	14	do.	do.	June 17	132	4	16	19
69	13	5	8	do.	June 5	do.	83	7	13	19
70	25	14	11	do.	June 6	do.	206	8	12	19
71	25	13	12	do.	June 8	June 20	66	10	13	22

TABLE XXXII.—Oviposition by codling moths of the spring brood in rearing cages, Grand Junction, Colo., 1916—Continued.

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male.	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition.	From date of emergence to last oviposition.
72	23	10	13	May 29	June 10	June 16	154	12	7	18
73	25	10	15	May 30	June 2	June 13	39	3	12	14
74	28	12	16	..do..	..do..	June 18	95	3	17	19
75	27	14	13	..do..	June 5	June 15	174	6	11	16
76	27	7	20	..do..	..do..	June 18	98	6	14	19
77	25	14	11	..do..	June 9	June 15	25	10	7	16
78	27	13	14	..do..	June 10	June 16	35	11	7	17
79	15	8	7	May 31	June 5	June 18	61	5	14	18
80	24	16	8	..do..	June 6	June 17	126	6	12	17
81	25	14	11	..do..	June 10	..do..	58	10	8	17
82	24	10	14	..do..	..do..	June 20	44	10	11	20
83	25	14	11	..do..	..do..	June 25	67	10	16	25
84	16	7	9	June 1	June 5	June 18	252	4	14	17
85	24	10	14	..do..	June 8	..do..	126	7	11	17
86	24	16	8	..do..	..do..	..do..	203	7	11	17
87	23	10	13	..do..	June 10	June 17	46	9	8	16
88	24	14	10	June 2	June 7	..do..	188	5	11	15
89	25	14	11	..do..	June 8	June 16	80	6	9	14
90	24	5	19	June 3	June 5	June 14	106	2	10	11
91	22	11	11	..do..	June 6	June 20	171	3	15	17
92	25	13	12	..do..	June 8	..do..	73	5	13	17
93	25	9	16	..do..	June 10	June 17	34	7	8	14
94	24	12	12	June 4	June 6	June 24	269	2	19	20
95	24	9	15	..do..	June 7	June 21	327	3	15	17
96	26	11	15	..do..	June 9	..do..	158	5	13	17
97	28	14	14	..do..	June 10	June 20	95	6	11	16
98	24	12	12	June 5	..do..	June 21	94	5	12	16
99	23	11	12	..do..	June 12	June 26	139	7	15	21
100	11	4	7	..do..	June 14	June 18	10	9	5	13
101	25	13	12	June 6	June 8	June 20	103	2	13	14
102	25	10	15	..do..	June 9	July 2	376	3	24	26
103	19	9	10	..do..	June 11	June 19	25	5	9	13
104	30	17	13	June 7	June 9	June 21	342	2	13	14
105	28	14	14	June 8	June 10	..do..	152	2	12	13
106	30	13	17	..do..	June 11	..do..	266	3	11	13
107	24	15	9	June 9	..do..	June 20	138	2	10	11
108	26	12	14	..do..	June 14	June 19	92	5	6	10
109	25	15	10	June 10	June 13	June 17	59	3	5	7
110	12	5	7	..do..	..do..	..do..	98	3	5	7
111	25	13	12	June 11	..do..	June 18	106	2	6	7
112	28	9	19	..do..	..do..	June 30	350	2	18	19
113	32	17	15	June 12	June 14	July 2	290	2	19	20
114	33	18	15	June 13	June 16	July 5	297	3	20	22
115	32	11	21	June 14	June 17	July 2	224	3	16	18
116	22	8	14	June 15	..do..	..do..	208	2	16	17
117	20	9	11	June 16	June 19	June 27	40	3	9	11
118	10	4	6	June 17	..do..	June 28	157	2	10	11
119	14	3	11	June 18	June 25	June 25	4	7	1	7
120	8	1	7	June 19	June 26	July 7	13	7	12	18
121	13	3	10	June 20	July 1	July 3	11	11	3	13
122	2	1	1	June 22	..do..	..do..	1			
123	4	1	3	June 23	July 2	July 7	7	9	6	14
Average								6.07	13.38	18.46
Maximum								13	32	34
Minimum								2	1	7

Number of male moths.....	1,292
Number of female moths.....	1,449
Total number of moths.....	2,741
Total number of eggs.....	16,435
Average number of eggs per female moth.....	11.34

Length of life of moths.—As in the previous season, the dead moths were removed daily from the oviposition cages and the date of their death recorded. From these records the length of life of 2,738 moths was computed. As shown in Table XXXIII, the

average length of life of 1,281 male moths was 14.67 days, maximum 35 days, minimum 1 day; the average length of life of 1,457 female moths was 15.73 days, maximum 39 days, minimum 1 day.

TABLE XXXIII.—*Length of life of male and female codling moths of the spring brood in captivity: Summary of records of 2,738 individual moths, Grand Junction, Colo., 1916.*

Male.		Female.		Male.		Female.		Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.
<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	
1	9	1	6	15	64	15	96	29	7	29	13
2	7	2	4	16	56	16	96	30	12	30	6
3	6	3	6	17	59	17	88	31	3	31	4
4	14	4	11	18	50	18	70	32	6	32	6
5	29	5	12	19	43	19	68	33	5	33	4
6	46	6	18	20	64	20	94	34	3	34	2
7	64	7	41	21	48	21	70	35	2	35	3
8	79	8	40	22	39	22	41	36	0	36	0
9	48	9	73	23	27	23	40	37	0	37	0
10	88	10	75	24	30	24	27	38	0	38	1
11	78	11	77	25	18	25	23	39	0	39	1
12	56	12	93	26	27	26	23				
13	86	13	98	27	10	27	14				
14	84	14	99	28	14	28	14	Total..	1,281	Total..	1,457

Average length of life of male moths, 14.67 days; female moths, 15.73 days.
Maximum length of life of male moths, 35 days; female moths, 39 days.
Minimum length of life of male moths, 1 day; female moths, 1 day.

THE FIRST GENERATION.

EGGS OF THE FIRST BROOD.

Time of egg deposition.—In Table XXXIV and figure 20 it will

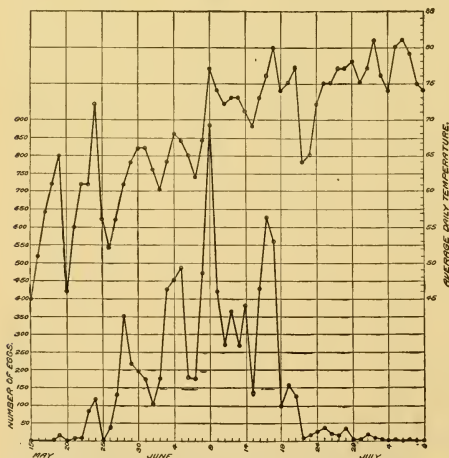


FIG. 20.—Time of deposition of eggs of the first brood of the codling moth, Grand Junction, Colo., 1916.

be observed that the first eggs of the first brood were deposited May 19, and the last July 7, the period of deposition covering about 7 weeks. The eggs laid on the latter date, however, were infertile, but the single egg deposited July 5 completed its development and hatched on July 11. The largest number of eggs laid in one day was 883 on June 9, and this date was approximately the middle of the oviposition period.

TABLE XXXIV.—Time of deposition, length of incubation, and time of hatching of eggs of the first brood of the codling moth, Grand Junction, Colo., 1916.

Observation No.	Number of eggs deposited.	Date—				Number of eggs hatched.	Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.		Red ring.	Black spot.	
							Days.	Days.	Days.
1	16	May 19	May 29	May 30	June 1	14	10	11	13
2					June 2	2			14
3	7	May 21	May 24	May 30	June 1	3	3	9	11
4					June 2	4			12
5	12	May 22	May 24	May 31	do.	7	2	9	11
6					June 3	5			12
7	86	May 23	May 25	May 31	June 2	4	2	8	10
8					June 3	24			11
9					June 4	45			12
10	117	May 24	May 28	May 30	June 3	2	4	6	10
11					June 4	60			11
12					June 5	18			12
13					June 6	2			13
14	2	May 25	May 29	June 4	June 5	2	4	10	11
15	38	May 26	do.	do.	do.	28	3	9	10
16					June 6	8			11
17	130	May 27	May 29	June 5	do.	108	2	9	8
18					June 7	12			9
19	353	May 28	May 30	June 6	do.	304	2	9	10
20					June 8	21			11
21	218	May 29	May 31	June 7	do.	176	2	7	8
22					June 9	20			9
23	194	May 30	June 2	June 8	do.	173	3	9	10
24					June 10	4			11
25	177	May 31	June 3	June 9	do.	141	3	9	10
26					June 11	2			11
27	106	June 1	June 4	June 9	June 10	70	3	8	9
28					June 11	12			10
29					June 12	2			11
30	179	June 2	June 6	June 10	June 11	143	4	8	9
31					June 12	7			10
32	425	June 3	June 6	June 10	June 11	272	3	7	8
33					June 12	55			9
34	451	June 4	June 7	June 11	do.	307	3	7	8
35					June 13	27			9
36	486	June 5	June 8	June 12	do.	403	3	7	8
37	180	June 6	June 9	do.	do.	101	3	6	7
38					June 14	40			8
39					June 15	5			9
40	176	June 7	June 9	June 13	June 14	93	2	6	7
41					June 15	23			8
42	471	June 8	June 10	June 14	do.	320	2	6	7
43					June 16	47			8
44	883	June 9	June 11	June 15	do.	539	2	6	7
45					June 17	247			8
46					June 18	35			9
47	420	June 10	June 11	June 16	June 17	210	1	6	7
48					June 18	63			8
49	272	June 11	June 13	June 17	June 19	239	2	6	7
50	361	June 12	June 14	June 18	June 19	245	2	6	7
51					June 20	29			8
52	267	June 13	June 15	June 19	do.	131	2	6	7
53	380	June 14	June 17	June 20	June 21	251	3	6	7
54	136	June 15	do.	do.	do.	49	2	5	6
55					June 22	31			7
56	429	June 16	June 18	June 21	do.	9	2	5	6
57					June 23	279			7
58					June 24	30			8
59	623	June 17	June 19	June 23	do.	355	2	6	7
60					June 25	19			8
61	558	June 18	June 20	June 24	do.	402	2	6	7
62					June 26	22			8
63	103	June 19	June 21	June 25	do.	37	2	6	7
64					June 27	25			8
65					June 28	3			9
66	158	June 20	June 22	June 26	June 27	46	2	6	7
67	125	June 21	June 24	June 27	June 28	31	3	6	7
68					June 29	31			8
69	8	June 22	June 25	June 28	do.	8	3	6	7
70	16	June 23	do.	do.	June 30	6	2	5	7
71	29	June 24	June 26	June 29	do.	15	2	5	6
72					July 1	4			7
73					July 2	5			8
74	37	June 25	June 27	July 1	do.	33	2	6	8
75	21	June 26	June 28	July 2	July 3	16			8
76	16	June 27	June 30	do.	do.	6	3	5	7

TABLE XXXIV.—*Time of deposition, length of incubation, and time of hatching of eggs of the first brood of the codling moth, Grand Junction, Colo., 1916—Continued.*

Observation No.	Number of eggs deposited.	Date—				Number of eggs hatched.	Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.		Red ring.	Black spot.	
77	35	June 28	June 30	July 3	July 4	12	Days. 2	Days. 5	Days. 7
78	3	June 29	July 1	July 4	July 5	1	2	5	6
79	3	June 30	July 3	.....	.....	0	3	.....	0
80	15	July 1	..do	July 6	July 7	9	2	5	6
81	8	July 2	July 4	July 7	July 8	5	2	5	6
82	.....	.....	.....	.....	July 9	2	.....	.....	7
83	4	July 3	.....	.....	.....	0	.....	.....	0
84	1	July 5	July 8	July 10	July 11	1	3	5	6
85	2	July 7	.....	.....	.....	0	.....	.....	0
Total.	8,774	.....	.....	.....	.....	6,597	.....	.....	.....
		Aver. ....	.....	.....	.....		2.62	6.68	7.32
		Max. ....	.....	.....	.....		10	11	14
		Min. ....	.....	.....	.....		1	5	6

Length of incubation.—The length of incubation and embryological changes of eggs of the first brood are given in Table XXXIV as follows: Average number of days from date of deposition to the appearance of the red ring 2.62 days, maximum 10 days, minimum 1 day; average appearance of the black spot from time of deposition 6.68 days, maximum 11 days, minimum 5 days; average incubation period 7.32 days, maximum 14 days, minimum 6 days.

LARVÆ OF THE FIRST BROOD.

Time of hatching.—The time of hatching of eggs of the first brood will be found in Table XXXIV. The first eggs of this brood

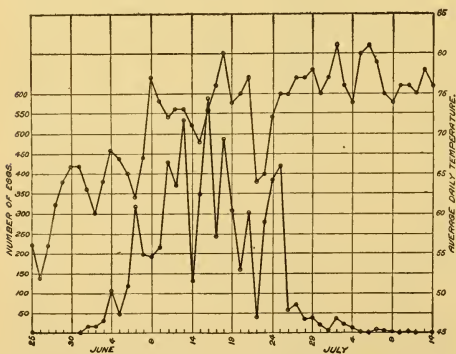


FIG. 21.—Time of hatching of eggs of the first brood of the codling moth, Grand Junction, Colo., 1916.

hatched June 1; the last, July 11. Thus the period of incubation extended over one month, the maximum number hatching on June 16, or 15 days after the first larvæ appeared. The rate of hatching is shown diagrammatically in figure 21, in which it will be noted that the majority of the larvæ hatched about the middle of the hatching period.

Length of the feeding period, stock-jar method.—The summarized account of the length of the feeding period of 817 larvæ of the first

brood, stock-jar method, will be found in Table XXXV. The first larvæ, as will be noted therein, entered the fruit June 8, while the last larvæ began feeding July 10. The average length of the feeding period was 20.19 days, maximum 42 days, and minimum 14 days.

Length of the feeding period, bagged-fruit method.—In Table XXXVI is given the length of the feeding period of 264 larvæ of the first brood according to the bagged-fruit method. In this study the first larvæ entered the fruit June 1, the last June 28. Reference to the summary of the table will show that the average feeding period was 21.10 days, maximum 29 days, and minimum 17 days.

TABLE XXXV.—*Length of feeding period of larvæ of the first brood of the codling moth, stock-jar method, Grand Junction, Colo., 1916.*

Date of entering fruit.	Number of individuals.	Length of feeding period in specified days.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	42																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
June	8	30	...	...	2	5	5	8	6	1	2	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Days.

Average length of feeding period 20.19
 Maximum length of feeding period 42
 Minimum length of feeding period 14

TABLE XXXVI.—Length of feeding period of codling-moth larvæ of the first brood, bagged-fruit method, Grand Junction, Colo., 1916.

Date of entering fruit.		Number of individuals.	Length of feeding period in specified days.																
			17	18	19	20	21	22	23	24	25	26	27	28	29				
June	1	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	2	2	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	3	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	4	7	.....	2	.....	1	.....	1	2	.....	.....	.....	.....	.....	.....	.....	.....		
	5	6	.....	.....	1	.....	4	.....	1	.....	.....	.....	.....	.....	.....	.....	.....		
	6	34	.....	1	7	.....	8	7	5	2	2	.....	.....	.....	.....	.....	.....		
	7	27	.....	3	10	5	3	2	4	.....	.....	.....	.....	.....	.....	.....	.....		
	8	7	.....	1	.....	3	1	.....	1	.....	.....	.....	.....	.....	.....	.....	.....		
	9	2	.....	.....	1	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	10	5	.....	.....	.....	1	1	2	1	.....	.....	.....	.....	.....	.....	.....	.....		
	11	10	1	.....	3	1	1	2	1	.....	1	.....	.....	.....	.....	.....	.....		
	12	5	.....	1	.....	.....	2	.....	.....	1	.....	.....	.....	.....	.....	.....	.....		
	13	23	1	2	10	2	2	4	.....	1	.....	.....	.....	.....	.....	.....	.....		
	14	10	.....	.....	2	2	.....	1	1	2	1	.....	.....	.....	.....	.....	.....		
	15	10	.....	.....	3	1	2	.....	2	.....	.....	1	.....	.....	.....	.....	.....		
	16	15	1	1	3	7	2	.....	.....	1	.....	.....	.....	.....	.....	.....	.....		
	17	12	1	.....	2	6	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	18	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	19	5	.....	2	2	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	20	14	.....	1	2	2	5	1	2	.....	.....	.....	.....	.....	.....	.....	.....		
	21	3	.....	.....	.....	.....	1	1	1	.....	.....	.....	.....	.....	.....	.....	.....		
	22	2	.....	.....	.....	1	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	23	8	.....	.....	1	1	1	1	3	1	.....	.....	.....	.....	.....	.....	.....		
	24	16	.....	.....	3	2	3	1	3	.....	.....	.....	.....	.....	.....	.....	.....		
	25	23	1	2	3	1	5	7	4	.....	.....	.....	2	2	.....	.....	.....		
	26	7	.....	.....	2	.....	2	1	2	.....	.....	.....	.....	.....	.....	.....	.....		
	27	1	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	28	7	2	.....	4	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....		
		254	7	14	54	39	49	38	30	11	9	4	6	2	1	.....			

Days.

Average length of feeding period..... 21.10
 Maximum length of feeding period..... 29
 Minimum length of feeding period..... 17

Length of the cocooning period.—Table XXXVII gives the data for 761 larvæ, on the time which elapsed from the time each larva left the fruit until it pupated. Attention is drawn to the fact that 300, or nearly one-half, of these individuals formed their cocoons in 4 days, 195 in 5 days, and 89 in 6 days. The average cocooning period for all the larvæ was 5.53 days, the maximum 30 days, and the minimum 2 days.

TABLE XXXVIII.—*Time of pupation of transforming codling moth larvæ of the first brood, Grand Junction, Colo., 1916.*

Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.
June 25	3	July 5	49	July 14	23	July 23	7	Aug. 1	1
27	2	6	41	15	14	24	12	2	1
28	6	7	50	16	35	25	2	6	1
29	13	8	22	17	37	26	5	7	1
30	12	9	48	18	26	27	3	11	1
July 1	17	10	41	19	28	28	4		
2	27	11	37	20	30	29	1	Total..	766
3	21	12	43	21	21	30	3		
4	36	13	32	22	7	31	3		

Length of the pupal stage.—The data pertaining to the length of the pupal stage of first-brood pupæ began with the individuals that transformed June 25 and ended with the larva that pupated August 6. During this interval the variations in climatic conditions were not pronounced and, as a result, the range in the pupal period is not as great as with the spring-brood pupæ, it being from a minimum of 6 to a maximum of 19 days, with an average of 11.23 days. Out of a total of 638 pupæ, 284 had a pupal period of 12 days. For further details see Table XXXIX.

TABLE XXXIX.—*Length of the pupal stage of codling moth pupæ of the first brood, Grand Junction, Colo., 1916.*

Date of pupation.		Number of individuals.	Length of the pupal stage in specified days.												
			6	8	9	10	11	12	13	14	15	16	17	19	
June	25	3				1		2							
	27	2				1									
	28	6				2	4								
	29	12				1	7	4							
	30	12				2	9	1							
	July	1	17				8	8		1					
		2	26				10	9	4						
		3	20		1		2	5	9	2					
		4	35		1		2	15	15	1			1		
		5	46				2	8	22	14		1			
6		39				1	3	21	14						
7		49					7	17	23		2				
8		22					4	7	9		1				
9		47				2	13	22	9		1				
10		39				1	4	20	13		1				
11	36				1	6	20	9							
12	42				1	8	21	8		3					
13	30					8	7	14		1			1		
14	21				2	4	11	4							
15	13				3	5	4	1							
16	34				3	8	15	6		2					
17	37				1	4	13	15	4						
18	25				1	2	9	7	6						
19	26					4	7	10	5						
20	29	1				1	5	14	8						
21	21						7	12	2						
22	7						1	5	1						
23	7						1	3	2		1				
24	12						2	3	4		3				
25	2								1		1				
26	4								3		1				
27	3							1	1		1				
28	4								2		1				
29	1											1			
30	3						1	1			1				
31	3							1							
Aug.	1	1								2					
	1	1								1					
	1	1								1					
	6	1								1					
		638	1	2	1	31	149	284	108	52	6	2	1	1	

Days.

Average length of the pupal stage..... 11.23
 Maximum length of pupal stage..... 19
 Minimum length of pupal stage..... 6

MOTHS OF THE FIRST BROOD.

Time of emergence.—As in the studies of 1915 (p. 24), a record was kept of the time of emergence of first-brood moths reared from insectary-bred material in order to determine the approximate limits of the brood. In Table XL it will be noted that 829 moths issued from July 5 to August 19, inclusive; the same data are presented graphically with temperatures in figure 23. Records were also taken of the time of emergence of the moths that issued from the larvæ collected every three days in the Hamilton and Edwards orchards. The moths that issued up to August 13, inclusive, were used for oviposition purposes in preference to those from the insectary-bred material, because their rate of emergence corresponded more closely to that which would have occurred in the

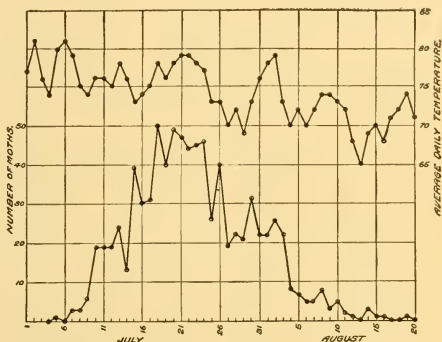


FIG. 23.—Time of emergence of codling moths of the first brood, insectary-bred material, Grand Junction, Colo., 1916.

field. These data are given in Table XLI and figure 24, and, as seen therein, the first moth emerged June 25. The rate of emergence, however, was very low until July 1, but on this date 17 moths issued.

The first moths of the second brood from insectary-bred material issued August 7, and the data indicate that from August 7 to 19 there was an overlapping of the moths of the first and second broods. Since there is no way of determining the brood to which the moths from field material belong, a date (Aug. 13) midway between that of the last emergence of the first-brood moths and the first emergence of the second-brood moths was taken as the dividing line between the two broods.

TABLE XLI.—Time of emergence of codling moths of the first brood, from material reared at the insectary, Grand Junction, Colo., 1916.

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
July 5	1	July 15	39	July 24	46	Aug. 2	26	Aug. 11	2
7	3	16	30	25	26	3	22	12	1
8	3	17	31	26	40	4	8	14	3
9	6	18	50	27	19	5	7	15	1
10	19	19	40	28	22	6	5	16	1
11	19	20	49	29	21	7	5	19	1
12	19	21	47	30	31	8	8		
13	24	22	44	31	22	9	3	Total...	829
14	13	23	45	Aug. 1	22	10	5		

TABLE XLI.—Time of emergence of codling moths of the first brood reared from field material, Grand Junction, Colo., 1916.

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
June 25	1	July 6	25	July 17	40	July 28	165	Aug. 8	152
26	0	7	42	18	68	29	96	9	117
27	0	8	28	19	70	30	93	10	133
28	2	9	16	20	53	31	94	11	132
29	1	10	45	21	91	Aug. 1	110	12	77
30	5	11	41	22	125	2	111	13	72
July 1	17	12	72	23	76	3	95		
2	9	13	51	24	121	4	76		
3	6	14	34	25	109	5	92		
4	30	15	59	26	83	6	111		
5	28	16	41	27	59	7	135		
									3,309

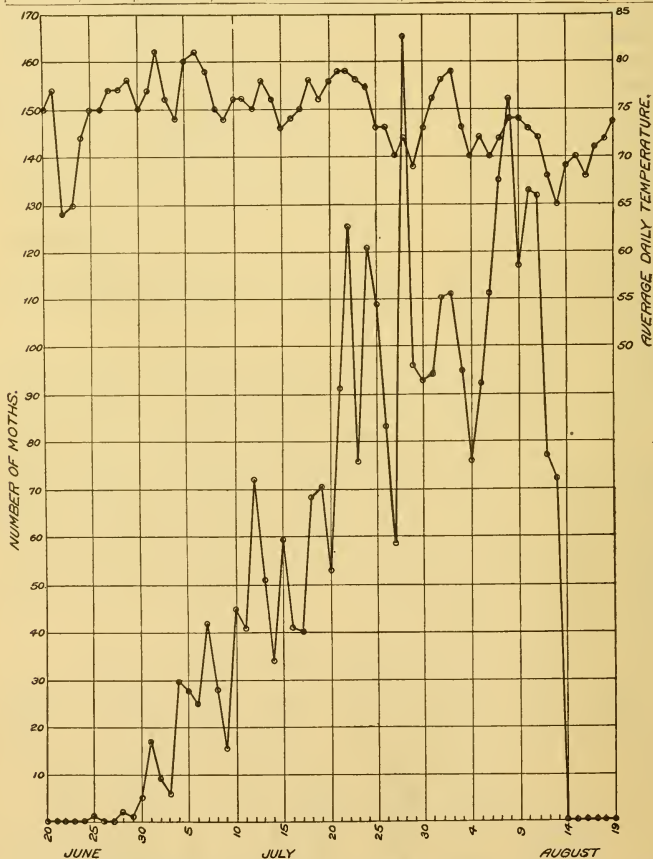


FIG. 24.—Time of emergence of codling moths of the first brood from band-collected material, Hamilton and Edwards orchards, Grand Junction, Colo., 1916.

Number of eggs per female moth.—The observations presented in Table XLII include 1,713 female moths which were confined with 1,596 male moths in 133 cages. These moths produced a total of 75,337 eggs, or an average of 43.98 eggs per female moth.

TABLE XLII.—*Oviposition by codling moths of the first brood in rearing cages, Grand Junction, Colo., 1916.*

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition.	From date of emergence to last oviposition.
.....	1			June 25						
.....	2			June 28						
.....	1			June 29						
.....	5			June 30						
.....	17			July 1						
1	26	11	15		July 3	July 15	812			
.....	9			July 2						
.....	6			July 3						
.....	11			July 4						
2	26	9	17		July 6	July 16	640			
3	19	10	9	July 4	do	July 17	315	2	12	13
4	28	14	14	July 5	do	July 16	322	1	11	11
5	25	6	19	July 6	July 8	do	753	2	9	10
6	21	13	8	July 7	do	July 24	398	1	17	17
7	21	14	7	do	July 11	July 18	134	4	8	11
8	28	14	14	July 8	do	July 23	541	3	13	15
9	16	4	12	July 9	do	July 28	256	2	18	19
10	22	8	14	July 10	do	July 24	161	1	14	14
11	23	15	8	do	July 12	July 23	479	2	12	13
12	21	9	12	July 11	do	July 16	125	1	5	5
13	20	15	5	do	July 13	July 20	219	2	8	9
14	26	14	12	July 12	do	July 28	352	1	16	16
15	20	9	11	do	July 15	July 23	516	3	9	11
16	26	10	16	do	do	July 24	204	3	10	12
17	25	12	13	July 13	July 14	July 27	612	1	14	14
18	26	13	13	do	July 16	July 28	357	3	13	15
19	34	17	17	July 14	July 15	July 26	1,020	1	12	12
20	33	12	21	July 15	July 17	July 30	900	2	14	15
21	26	12	14	do	July 21	July 27	85	6	7	12
22	26	10	16	July 16	July 17	Aug. 1	1,222	1	16	16
23	15	3	12	do	July 19	July 30	184	3	12	14
24	24	12	12	July 17	July 18	July 28	665	1	11	11
25	16	6	10	do	July 19	July 30	436	2	12	13
26	25	13	12	July 18	do	Aug. 1	748	1	14	14
27	25	16	9	do	July 20	do	654	2	13	14
28	18	5	13	do	do	do	1,088	2	13	14
29	21	11	10	July 19	do	July 30	555	1	11	11
30	25	10	15	do	July 22	July 28	420	3	7	9
31	24	14	10	do	do	July 30	579	3	9	11
32	26	12	14	July 20	do	July 31	794	2	10	11
33	27	8	19	do	July 23	July 28	341	3	6	8
34	24	7	17	July 21	July 22	July 31	281	1	10	10
35	21	5	16	do	do	Aug. 7	1,191	1	17	17
36	25	11	14	do	July 23	July 30	385	2	8	9
37	21	11	10	do	July 24	July 29	391	3	6	8
38	25	16	9	July 22	July 23	Aug. 4	791	1	13	13
39	24	14	10	do	July 24	Aug. 5	250	2	13	14
40	20	9	11	do	do	do	296	2	13	14
41	19	8	11	do	do	Aug. 7	536	2	15	16
42	24	12	12	do	do	Aug. 8	822	2	16	17
43	13	8	5	do	July 25	Aug. 4	228	3	11	13
44	26	14	12	July 23	July 24	Aug. 6	595	1	14	14
45	25	16	9	do	do	do	1,153	2	13	14
46	25	15	10	do	July 27	do	444	4	11	14
47	24	9	15	July 24	July 25	Aug. 4	1,013	1	11	11
48	25	11	14	do	do	Aug. 8	1,305	1	15	15
49	25	13	12	do	July 26	Aug. 9	1,017	2	15	16
50	23	8	15	do	do	Aug. 14	931	2	20	21
51	24	16	8	do	July 28	Aug. 4	540	4	8	11
52	28	16	12	July 25	July 27	Aug. 8	979	2	13	14
53	26	15	11	do	July 28	Aug. 7	802	3	11	13
54	27	11	16	do	do	do	1,423	3	11	13

TABLE XLII.—*Oviposition by codling moths of the first brood in rearing cages, Grand Junction, Colo., 1916—Continued.*

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition.	From date of emergence to last oviposition.
55	28	16	12	July 28	July 28	Aug. 8	1,065	3	12	14
56	28	18	10	July 26	do.	do.	709	2	12	13
67	27	14	13	do.	do.	do.	1,018	2	12	13
58	28	10	18	do.	do.	Aug. 11	1,616	2	15	16
59	29	6	23	July 27	do.	Aug. 15	915	1	19	19
60	30	13	17	do.	July 29	Aug. 10	558	2	13	14
61	27	17	10	July 28	July 30	do.	276	2	12	13
62	28	13	15	do.	do.	Aug. 13	381	2	15	16
63	28	20	8	do.	July 31	Aug. 7	107	3	8	10
64	28	23	5	do.	do.	Aug. 8	341	3	9	11
65	28	13	15	do.	do.	Aug. 11	606	3	12	14
66	26	9	17	do.	do.	Aug. 12	1,016	3	13	15
67	24	11	13	July 29	do.	do.	601	2	13	14
68	22	10	12	do.	do.	Aug. 15	1,171	2	16	17
69	24	12	12	do.	do.	Aug. 16	277	2	17	18
70	26	20	6	do.	Aug. 1	Aug. 11	432	3	11	13
71	20	13	7	July 30	July 31	do.	408	1	12	12
72	24	15	9	do.	Aug. 1	Aug. 14	344	2	14	15
73	24	14	10	do.	do.	do.	427	2	14	15
74	25	8	17	do.	Aug. 2	do.	442	3	13	15
75	24	5	19	July 31	Aug. 1	Aug. 15	197	1	15	15
76	25	15	10	do.	Aug. 2	Aug. 8	199	2	7	8
77	24	10	14	do.	do.	Aug. 11	468	2	10	11
78	21	9	12	do.	Aug. 3	Aug. 12	455	3	10	12
79	28	13	15	Aug. 1	do.	Aug. 16	565	2	14	15
80	26	15	11	do.	do.	Aug. 17	1,054	2	15	16
81	29	11	18	do.	do.	Aug. 21	991	2	19	20
82	27	12	15	do.	do.	do.	1,484	2	19	20
83	29	6	23	Aug. 2	Aug. 4	Aug. 19	1,144	2	16	17
84	27	10	17	do.	Aug. 5	Aug. 14	323	3	10	12
85	28	9	19	do.	do.	Aug. 19	415	3	15	17
86	27	10	17	do.	Aug. 6	Aug. 13	562	4	8	11
87	25	11	14	Aug. 3	Aug. 5	Aug. 11	608	2	4	8
88	25	14	11	do.	do.	Aug. 14	484	2	10	11
89	25	10	15	do.	do.	Aug. 16	680	2	12	13
90	20	10	10	do.	Aug. 6	Aug. 18	373	3	13	15
91	22	5	17	Aug. 4	do.	Aug. 17	457	2	12	13
92	22	12	10	do.	do.	Aug. 22	652	2	17	18
93	32	8	24	do.	Aug. 7	Aug. 17	335	3	11	13
94	25	10	15	Aug. 5	Aug. 6	Aug. 22	1,043	1	17	17
95	25	6	19	do.	do.	Aug. 25	502	1	20	20
96	25	15	10	do.	Aug. 7	do.	468	2	19	20
97	17	15	2	do.	Aug. 10	Aug. 10	3	5	1	5
98	26	7	19	Aug. 6	Aug. 7	Aug. 15	126	1	9	9
99	28	10	18	do.	do.	Aug. 17	950	1	11	11
100	28	16	12	do.	Aug. 8	Aug. 21	575	2	14	15
101	29	10	19	do.	do.	Aug. 24	1,048	2	17	18
102	26	19	7	Aug. 7	do.	Aug. 19	247	1	12	12
103	28	14	14	do.	Aug. 9	Aug. 18	173	2	10	11
104	26	11	15	do.	do.	do.	511	2	10	11
105	27	18	9	do.	do.	Aug. 22	479	2	14	15
106	28	12	16	do.	Aug. 10	Aug. 24	143	3	15	17
107	27	17	10	Aug. 8	Aug. 9	Aug. 26	155	1	18	18
108	25	13	12	do.	do.	do.	785	1	18	18
109	25	9	16	do.	Aug. 10	Aug. 19	332	2	10	11
110	25	13	12	do.	do.	Aug. 20	234	2	11	12
111	25	16	9	do.	do.	Aug. 26	388	2	17	18
112	25	14	11	do.	Aug. 11	Aug. 18	218	3	8	10
113	25	15	10	Aug. 9	Aug. 10	Aug. 23	517	1	14	14
114	25	10	15	do.	do.	do.	733	2	14	14
115	25	11	14	do.	Aug. 11	Aug. 22	710	2	12	13
116	24	9	15	do.	do.	Aug. 26	755	2	16	17
117	18	8	10	do.	Aug. 14	do.	377	5	13	17
118	27	11	16	Aug. 10	Aug. 12	Aug. 27	376	2	16	17
119	25	12	13	do.	do.	do.	568	2	16	17
120	28	12	16	do.	Aug. 14	Aug. 26	707	4	13	16
121	26	14	12	do.	do.	Aug. 29	624	4	16	19
122	27	14	13	do.	do.	Aug. 30	571	4	17	20
123	27	12	15	Aug. 11	Aug. 13	Aug. 27	703	2	15	16
124	25	13	12	do.	do.	Aug. 29	346	2	17	18
125	27	16	11	do.	Aug. 14	Aug. 21	146	3	8	10
126	26	16	10	do.	do.	Aug. 22	445	3	9	11

TABLE XLII.—*Oviposition by codling moths of the first brood in rearing cages, Grand Junction, Colo., 1916—Continued.*

Cage No.	Number of moths.	Sex.		Date of—			Total number of eggs deposited.	Number of days—		
		Male.	Female.	Emergence of moths.	First oviposition.	Last oviposition.		Before oviposition.	Of oviposition.	From date of emergence to last oviposition.
127	27	14	13	Aug. 11	Aug. 14	Aug. 27	84	3	14	16
128	25	13	12	Aug. 12	...do...	Aug. 28	643	2	15	16
129	26	18	8	...do...	Aug. 15	Aug. 23	190	3	9	11
130	26	17	9	...do...	...do...	Aug. 26	406	3	12	14
131	25	17	8	Aug. 13	...do...	Aug. 29	146	2	15	16
132	25	12	13	...do...	...do...	...do...	735	2	15	16
133	22	11	11	...do...	Aug. 16	Aug. 31	609	3	16	18
Total...	3,309	1,596	1,713	.....	.....	.....	75,337	.....	.....	.....
Ave.....								2.21	12.69	13.63
Max.....								5	20	20
Min.....								1	1	5

Average number of eggs per female moth, 43.98.

Time of oviposition.—As previously mentioned, the moths that issued up to August 13, inclusive, from the larvæ collected every three days from banded trees in the Hamilton and Edwards orchards, were employed for the oviposition studies.

It will be noted in the summary of this table that the average number of days from the date of emergence to the first oviposition was 2.21, maximum 5 days, minimum 1 day; the average number of days of oviposition was 12.69 days, maximum 20 days, minimum 1 day; the average number of days from the time of emergence to last oviposition was 13.63, maximum 20 days, minimum 5 days.

Length of life of moths.—A record was kept of the length of life of 3,231 moths of the first brood of which 1,561 were of the male sex and 1,670 of the female sex. According to the mortality data given in Table XLIII, the average length of life of the male moths was 13.12 days and of the female moths 12.20 days. The maximum length of life of the male moths was 38 days, female moths 26 days; minimum length of life of both the male and female moths 1 day.

TABLE XLIII.—*Length of life of male and female coaling moths of the first brood in captivity: Summary of records of 3,231 individual moths, Grand Junction, Colo., 1916.*

Male.		Female.		Male.		Female.		Male.		Female.	
Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.	Length of life.	Number of moths.
<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>		<i>Days.</i>	
1	11	1	6	15	76	15	111	29	5	29	0
2	12	2	9	16	81	16	89	30	4	30	0
3	8	3	7	17	75	17	65	31	0	31	0
4	18	4	15	18	65	18	51	32	1	32	0
5	13	5	20	19	56	19	40	33	0	33	0
6	36	6	33	20	51	20	29	34	0	34	0
7	49	7	70	21	42	21	18	35	0	35	0
8	107	8	99	22	35	22	12	36	0	36	0
9	151	9	147	23	22	23	9	37	0	37	0
10	137	10	172	24	12	24	4	38	1	38	0
11	141	11	195	25	13	25	1				
12	124	12	156	26	5	26	1				
13	102	13	169	27	4	27	0	Total..	1,561	Total..	1,670
14	103	14	142	28	1	28	0				

Average length of life of male moths, 13.12 days; female moths, 12.20 days.

Maximum length of life of male moths, 38 days; female moths, 26 days.

Minimum length of life of male moths, 1 day; female moths, 1 day.

LIFE CYCLE OF THE FIRST GENERATION.

Life cycle, stock-jar feeding method.—The summarized data giving the average length of each stage in the life cycle of the codling moth, first generation, are given in Table XLIV. These data are derived from the observations of 550 individuals reared by the stock-jar feeding method. By reference to this table it will be found that the average length of the incubation period was 7.67 days, larval feeding period 19.33 days, cocooning period 5.61 days, and pupal period 12.26 days. The average life cycle was 44.89 days and the average complete life cycle 47.10 days, obtained by adding to the life cycle 2.21 days, which is the average time that elapsed from the emergence of the moths to the deposition of the first egg.

Life cycle, bagged-fruit feeding method.—In Table XLV the results of rearing 188 individuals of the first generation from the egg to the adult stage, bagged-fruit method, are given. By reference to this table it will be seen that the average incubation period was 8.56 days, the larval feeding period 20.45 days, cocooning period 5.26 days, pupal period 11.86 days, average life cycle 46.37 days, and the average complete life cycle 48.58 days.

TABLE XLIV.—*Life cycle of the first generation of the codling moth, as observed by rearing, stock-jar feeding method, Grand Junction, Colo., 1916.*

Date of egg deposition.	Number of individuals.	Incubation.	Larval feeding period.			Coeooning period.			Pupal period.			Life cycle. ¹		
			Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
			<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
May 29	29	10	18.79	23	16	6.37	30	4	12.03	17	8	47.20	77	41
30	25	10	18.80	24	15	5.52	9	4	12.24	16	10	46.56	57	39
31	16	10	19.12	22	17	4.62	9	3	11.87	14	10	45.62	52	40
June 3	60	8	19.63	24	15	6.06	16	4	12.18	14	10	45.88	59	40
4	32	8	19.93	24	16	5.34	12	2	12.25	13	11	45.53	52	40
5	37	8	20.27	26	18	5.94	18	4	12.62	14	11	46.83	59	42
7	13	7	19.46	23	17	4.15	6	3	12.15	13	10	42.76	47	38
8	30	7	18.60	27	15	5.66	16	3	12.23	15	11	45.50	61	37
9	47	7	19.55	25	16	6.61	15	3	12.42	14	11	45.59	55	39
9	34	8	19.82	34	15	6.08	12	4	12.29	14	10	45.20	62	39
11	25	7	18.16	26	15	5.56	12	3	11.88	15	10	42.60	58	37
12	18	7	19.66	30	17	5.16	13	4	12.33	15	10	44.16	57	38
13	13	7	19.38	25	17	5.53	11	4	12.84	19	11	44.76	51	41
14	19	7	19.63	29	16	4.47	9	3	11.94	14	10	43.05	54	37
15	26	7	18.57	26	14	5.34	12	3	11.73	14	6	42.65	57	36
16	4	7	18.75	22	15	4.25	5	4	11.25	13	10	41.25	47	37
17	52	7	19.44	26	15	5.51	13	3	12.65	15	11	44.61	54	37
18	32	7	19.37	28	16	6.25	19	4	12.40	15	10	45.03	58	39
19	12	7	20.66	26	16	3.91	5	3	12.00	13	10	43.58	51	35
20	16	7	17.81	22	16	4.56	8	4	12.25	13	11	41.62	46	38
21	1	7	16.00	16	16	5.00	5	5	12.00	12	12	40.00	40	40
21	3	8	18.33	20	16	3.66	4	3	12.66	13	12	42.66	45	41
24	1	6	19.00	19	19	4.00	4	4	12.00	12	12	41.00	41	41
28	3	6	21.33	23	20	5.33	6	5	12.33	14	11	45.00	49	43
July 1	1	6	16.00	16	16	3.00	3	3	13.00	13	13	38.00	38	38
2	1	6	19.00	19	19	4.00	4	4	14.00	14	14	43.00	43	43
	550	7.67	19.33	34	14	5.61	30	2	12.26	19	6	44.89	77	36

¹ Add 2.21 days for complete life cycle.TABLE XLV.—*Life cycle of the first generation of the codling moth, as observed by rearing, bagged-fruit feeding method, Grand Junction, Colo., 1916.*

Date of egg deposition.	Number of individuals.	Incubation.	Larval feeding period.			Coeooning period.			Pupal period.			Life cycle. ¹		
			Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
			<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
May 19	1	13	19.00	19	19	5.00	5	5	10.00	10	10	47.00	47	47
22	2	11	22.00	25	19	4.00	4	4	11.50	12	11	49.50	51	46
24	6	11	20.66	23	18	3.66	5	3	11.00	12	10	46.33	50	44
26	6	10	21.00	23	19	4.33	5	3	11.16	12	11	46.50	49	44
27	28	10	21.46	27	18	5.25	11	3	11.42	14	8	48.14	58	42
28	24	10	21.25	24	19	6.62	18	9	12.00	14	9	49.87	66	41
29	7	10	21.71	25	18	4.71	7	3	11.42	13	10	47.85	52	45
30	1	10	19.00	19	19	4.00	4	4	12.00	12	12	45.00	45	45
31	5	10	21.60	23	20	4.20	5	4	11.40	12	10	47.20	50	44
June 3	9	8	20.55	25	17	4.44	6	4	11.66	13	10	44.66	49	41
4	4	8	21.75	27	18	4.50	5	4	12.75	13	12	47.00	52	44
5	22	8	20.64	25	17	4.95	15	3	11.90	14	11	44.50	57	40
7	6	7	21.33	25	19	5.50	8	3	12.00	13	10	45.83	50	42
8	6	7	19.83	21	19	5.00	6	4	12.16	13	12	41.00	46	42
9	9	7	19.77	24	17	4.66	7	2	11.88	13	11	43.33	49	39
9	8	8	19.62	22	17	6.70	19	4	11.62	13	11	45.75	62	40
12	5	7	19.00	21	18	4.20	5	4	12.20	13	12	42.40	44	41
13	7	7	20.00	23	18	7.00	18	4	11.70	13	10	45.71	60	39
14	1	7	22.00	22	22	4.00	4	4	13.00	13	13	45.00	46	46
15	1	7	20.00	20	20	4.00	4	4	10.00	10	10	41.00	41	41
16	4	7	21.50	24	19	4.75	6	4	12.50	14	11	45.75	49	41
17	4	7	20.25	21	19	5.00	6	4	12.25	14	11	44.50	47	43
18	11	7	20.72	23	17	7.27	19	3	12.45	14	10	47.45	62	38
19	3	7	21.66	23	21	4.66	5	4	13.33	14	13	46.66	48	46
20	1	7	18.00	18	18	5.00	5	5	12.00	12	12	42.00	42	42
21	7	7	18.85	22	17	3.57	5	2	13.14	15	12	42.59	49	40
	188	8.56	20.45	27	17	5.26	19	2	11.86	15	8	46.37	66	38

¹ Add 2.21 days for complete life cycle.

THE SECOND GENERATION.

EGGS OF THE SECOND BROOD.

Time of deposition.—As given in Table XLVI, eggs of the second brood were deposited from July 3 to August 31, inclusive, and during this period 46,410 eggs were laid. These data were obtained by confining the moths that emerged from the larvæ collected in the

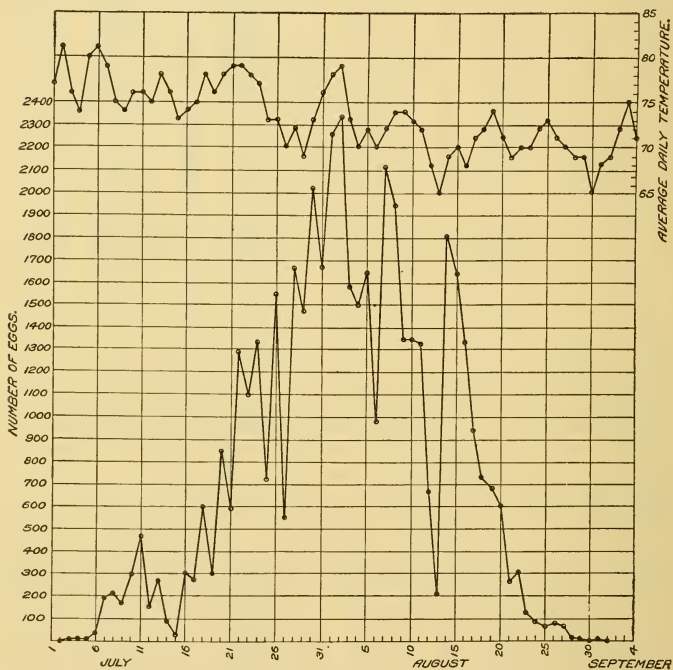


FIG. 25.—Time of deposition of eggs of the second brood of the codling moth, Grand Junction, Colo., 1916.

field, using all of the moths that issued up to August 13, inclusive. The greatest number of eggs laid on any one day was 2,333, and these were deposited on August 2. The time of egg deposition is shown graphically with average daily temperatures in figure 25.

TABLE XLVI.—Time of deposition, length of incubation, and time of hatching of eggs of the second brood of the codling moth, Grand Junction, Colo., 1916.

Observation No.	Number of eggs deposited.	Date—				Number of eggs hatched.	Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.		Red ring.	Black spot.	
1	13	July 3	July 5	July 8	July 9	12	Days. 2	Days. 5	Days. 6
2	4	July 4	July 6	July 9	July 10	3	2	5	6
3	1	July 5	July 7	July 10	July 11	1	2	5	6
4	36	July 6	July 8	July 11	July 12	31	2	5	6
5	190	July 7	July 9	July 12	July 13	131	2	5	6
6					July 14	34			7
7					July 15	15			8
8	213	July 8	July 10	July 13	July 14	177	2	5	6
9					July 15	21			7
10	170	July 9	July 11	July 14	do.	138	2	5	6
11					July 16	24			7
12	288	July 10	July 12	July 15	do.	112	2	5	6
13					July 17	147			7
14					July 18	6			8
15	468	July 11	July 13	July 16	July 17	351	2	5	6
16					July 18	66			7
17	157	July 12	July 14	July 17	do.	100	2	5	6
18					July 19	24			7
19	270	July 13	July 15	July 18	do.	116	2	5	6
20					July 20	108			7
21	84	July 14	July 16	July 19	do.	42	2	5	6
22					July 21	23			7
23	28	July 15	July 17	July 20	do.	168	2	5	6
24					July 22	11			7
25					July 23	6			8
26	300	July 16	July 18	July 21	July 22	264	2	5	6
27					July 23	15			7
28	274	July 17	July 19	July 22	do.	260	2	5	6
29	596	July 18	July 20	July 23	July 24	519	2	5	6
30	292	July 19	July 21	July 24	July 25	274	2	5	6
31	846	July 20	July 22	July 25	July 26	635	2	5	6
32					July 27	152			7
33	593	July 21	July 23	July 26	do.	397	2	5	6
34					July 28	65			7
35					July 29	48			8
36	1,284	July 22	July 24	July 27	July 28	270	2	5	6
37					July 29	899			7
38	1,097	July 23	July 25	July 29	July 30	910	2	6	7
39					July 31	22			8
40	1,333	July 24	July 26	July 30	do.	946	2	6	7
41					Aug. 1	187			8
42	722	July 25	July 27	July 31	do.	541	2	6	7
43					Aug. 2	51			8
44	1,528	July 26	July 28	Aug. 1	do.	1,375	2	6	7
45					Aug. 3	31			8
46	553	July 27	July 29	Aug. 2	do.	431	2	6	7
47					Aug. 4	44			8
48	1,658	July 28	July 31	Aug. 3	do.	1,542	3	6	7
49	1,471	July 29	do.	do.	do.	338	2	5	6
50					Aug. 5	941			7
51					Aug. 6	118			8
52	2,019	July 30	Aug. 1	Aug. 4	Aug. 5	727	2	5	6
53					Aug. 6	1,171			7
54	1,674	July 31	Aug. 1	Aug. 5	do.	268	1	5	6
55					Aug. 7	1,289			7
56	2,256	Aug. 1	Aug. 3	Aug. 7	Aug. 8	2,098	2	6	7
57	2,333	Aug. 2	Aug. 4	Aug. 8	Aug. 9	1,890	2	6	7
58	1,582	Aug. 3	Aug. 6	Aug. 9	Aug. 10	1,345	3	6	7
59	1,499	Aug. 4	do.	Aug. 10	Aug. 11	1,364	2	6	7
60					Aug. 12	30			8
61	1,641	Aug. 5	Aug. 7	Aug. 11	do.	1,313	2	6	7
62					Aug. 13	131			8
63					Aug. 14	115			9
64	980	Aug. 6	Aug. 8	Aug. 12	Aug. 13	245	2	6	7
65					Aug. 14	696			8
66	2,115	Aug. 7	Aug. 9	Aug. 13	do.	338	2	6	7
67					Aug. 15	1,544			8
68					Aug. 16	64			9
69	1,944	Aug. 8	Aug. 10	Aug. 14	do.	1,613	2	6	8
70					Aug. 17	117			9
71	1,347	Aug. 9	Aug. 11	Aug. 14	do.	1,131	2	5	8
72	1,346	Aug. 10	Aug. 12	Aug. 17	Aug. 18	1,185	2	7	8
73					Aug. 19	67			9
74	1,322	Aug. 11	Aug. 14	Aug. 18	do.	1,190	3	7	8
75	662	Aug. 12	do.	Aug. 19	Aug. 20	549	2	7	8
76					Aug. 21	20			9

TABLE XLVI.—*Time of deposition, length of incubation, and time of hatching of eggs of the second brood of the codling moth, Grand Junction, Colo., 1916—Continued.*

Observation No.	Number of eggs deposited.	Date—				Number of eggs hatched.	Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.		Red ring.	Black spot.	
							<i>Days.</i>	<i>Days.</i>	<i>Days.</i>
77	212	Aug. 13	Aug. 16	Aug. 19	Aug. 20	155	3	6	7
78	1,806	Aug. 14	do	Aug. 20	Aug. 21	507	2	6	7
79					Aug. 22	1,300			8
80					Aug. 23	72			9
81	1,641	Aug. 15	Aug. 17	Aug. 22	do	1,411	2	7	8
82					Aug. 24	49			9
83	1,335	Aug. 16	Aug. 18	Aug. 22	Aug. 23	147	2	6	7
84					Aug. 24	975			8
85					Aug. 25	40			9
86	943	Aug. 17	Aug. 19	Aug. 24	do	811	2	7	8
87	723	Aug. 18	Aug. 20	Aug. 25	Aug. 26	578	2	7	8
88	689	Aug. 19	Aug. 21	do	do	145	2	6	7
89					Aug. 27	455			8
90					Aug. 28	34			9
91	613	Aug. 20	Aug. 22	Aug. 26	Aug. 27	80	2	6	7
92					Aug. 28	447			8
93	263	Aug. 21	Aug. 23	Aug. 27	do	8	2	6	7
94					Aug. 29	213			8
95	306	Aug. 22	Aug. 24	Aug. 29	Aug. 30	205	2	7	8
96					Aug. 31	46			9
97	132	Aug. 23	Aug. 25	Aug. 29	do	111	2	6	8
98					Sept. 1	11			9
99	89	Aug. 24	Aug. 26	Aug. 31	do	42	2	7	8
100					Sept. 2	35			9
101					Sept. 3	3			10
102	74	Aug. 25	Aug. 27	Sept. 1	Sept. 2	46	2	7	8
103					Sept. 3	21			9
104	80	Aug. 26	Aug. 28	Sept. 2	do	51	2	7	8
105					Sept. 4	10			9
106	65	Aug. 27	Aug. 29	Sept. 3	do	52	2	7	8
107					Sept. 5	9			9
108	18	Aug. 28	Aug. 30	Sept. 4	do	12	2	7	8
109					Sept. 6	2			9
110	9	Aug. 29	Sept. 1	Sept. 5	do	7	3	7	8
111	1	Aug. 30	do	do	do	1	2	6	7
112	12	Aug. 31	Sept. 2	Sept. 6	Sept. 8	10	2	6	8
Total.	46,410					43,624			
		Aver.					2.06	5.80	6.93
		Max.					3	7	10
		Min.					1	5	6

Length of incubation.—As previously noted, eggs of the second brood were deposited from July 3 to August 31, inclusive, and during this period observations of the length of incubation and embryological changes of these eggs were taken. The results in detail are shown in Table XLVI. From the data obtained it was found that the appearance of the red ring averaged 2.06 days from the time of deposition, maximum 3 days, minimum 1 day; the black spot appeared on an average of 5.80 days subsequent to the time of oviposition, maximum 7 days, minimum 5 days; the average total length of the incubation period was 6.93 days, maximum 10 days, minimum 6 days.

LARVÆ OF THE SECOND BROOD.

Time of hatching.—The hatching period of larvæ of the second brood is given in Table XLVI and, as appears therein, the first of these hatched July 9, while the last hatched September 8. In con-

nection with the control of the codling moth, the time of hatching of the second brood of eggs is of great importance, as is also the time when these eggs are hatching in largest numbers. It will be noted in this table and in figure 26 that the larvæ were appearing in greatest numbers during the middle of the hatching period. The maximum number of eggs, 2,098, hatched on August 8.

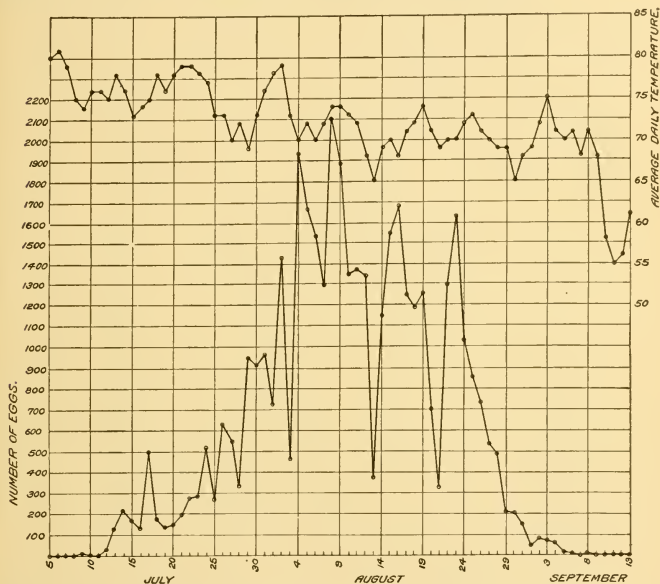


FIG. 26.—Time of hatching of eggs of the second brood of the codling moth, Grand Junction, Colo., 1916.

Length of the feeding period.—The data on the length of the feeding period of larvæ of the second brood, stock-jar method, are presented in detail in Table XLVII. The records are given for 2,569 larvæ, the dates of the entrance of which into the fruit and of leaving the fruit were observed. The summarized computations show that the average length of the feeding period of these larvæ was 28.61 days, maximum 70 days, minimum 14 days.

TABLE XLVIII.—*Length of cocooning period of transforming codling moth larvæ of the second brood, Grand Junction, Colo., 1916.*

Larvæ left fruit.	Number of indi- viduals.	Length of cocooning period in specified days, being the time from leaving the fruit to the time of pupation.												Ave.	Max.	Min.		
		2	3	4	5	6	7	8	9	10	12	14						
July 23	2	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	Days.	Days.	Days.	4.00	4	4
24	8	.....	.....	4	2	2	.....	.....	.....	.....	.....	.....	4.75	6	4	4.75	6	4
25	6	.....	.....	1	5	.....	.....	.....	.....	.....	.....	.....	4.83	5	4	4.83	5	4
26	15	.....	.....	5	8	2	.....	.....	.....	.....	.....	.....	4.80	6	4	4.80	6	4
27	18	.....	.....	8	9	1	.....	.....	.....	.....	.....	.....	4.61	6	4	4.61	6	4
28	15	.....	2	9	3	.....	1	.....	.....	.....	.....	.....	4.27	7	3	4.27	7	3
29	13	.....	3	8	2	.....	.....	.....	.....	.....	.....	.....	3.92	5	3	3.92	5	3
30	12	.....	7	2	3	.....	.....	.....	.....	.....	.....	.....	3.67	5	3	3.67	5	3
31	19	.....	2	5	7	3	2	.....	.....	.....	.....	.....	4.89	7	3	4.89	7	3
Aug. 1	10	.....	1	5	2	2	.....	.....	.....	.....	.....	.....	4.50	6	3	4.50	6	3
2	17	.....	.....	5	5	5	1	.....	.....	.....	1	.....	5.65	14	4	5.65	14	4
3	8	.....	.....	4	1	2	.....	1	.....	.....	.....	.....	5.13	8	4	5.13	8	4
4	6	.....	.....	4	2	.....	.....	.....	.....	.....	.....	.....	4.33	5	4	4.33	5	4
5	7	.....	1	2	3	1	.....	.....	.....	.....	.....	.....	4.43	6	2	4.43	6	2
6	3	.....	.....	1	2	.....	.....	.....	.....	.....	.....	.....	4.67	5	4	4.67	5	4
7	2	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	4.00	4	4	4.00	4	4
8	4	.....	.....	.....	1	1	1	.....	.....	.....	1	.....	7.50	12	5	7.50	12	5
9	1	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	6.00	6	6	6.00	6	6
10	1	.....	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	10.00	10	10	10.00	10	10
11	1	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	9.00	9	9	9.00	9	9
13	2	.....	.....	.....	.....	.....	1	.....	.....	1	.....	.....	8.50	10	7	8.50	10	7
14	1	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	5.00	5	5	5.00	5	5
Total...	171	1	15	67	56	20	6	1	1	2	1	1	4.80	14	2	4.80	14	2

PUPE OF THE SECOND BROOD.

Time of pupation.—The insectary reared larvæ of the second brood began pupating July 27, when 2 individuals transformed. The



FIG. 27.—Time of pupation of second brood of the codling moth, Grand Junction, Colo., 1916.

number of larvæ transforming daily increased up to August 1 and, as will be seen in Table XLIX and figure 27, 23 individuals pupated on this date. The last pupation occurred August 23.

Length of the pupal stage.—

Data on the length of the pupal stage of 160 pupæ of the second brood were obtained. These observations are recorded in Table L, and, as shown therein, the observations included pupæ that transformed from July 27 to Au-

gust 23. Owing to the fairly even climatic conditions during this period there was little difference in the length of the pupal stage, the range being from 11 to 16 days, with an average of 13.51 days.

TABLE XLIX.—*Time of pupation of transforming codling moth larvæ of the second brood, Grand Junction, Colo., 1916.*

Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.	Date of pupation.	Number of pupæ.
July 27	2	Aug. 2	19	Aug. 8	10	Aug. 14	1	Aug. 20	4
28	3	3	6	9	7	15	2	21	0
29	4	4	10	10	4	16	1	22	0
30	12	5	12	11	6	17	0	23	1
31	18	6	10	12	0	18	0		
Aug. 1	23	7	14	13	1	19	1	Total....	171

TABLE L.—*Length of the pupal stage of codling moth pupæ of the second brood, Grand Junction, Colo., 1916.*

Date of pupation.	Number of individuals.	Length of the pupal stage in specified days.						Date of pupation.	Number of individuals.	Length of the pupal stage in specified days.					
		11	12	13	14	15	16			11	12	13	14	15	16
July 27	1	1	---	---	---	---	---	Aug. 9	7	---	---	3	2	2	---
28	3	---	1	2	---	---	---	10	4	---	---	---	4	---	---
29	3	1	2	---	---	---	---	11	6	---	---	---	4	2	---
30	12	1	9	2	---	---	---	13	1	---	---	---	1	---	---
31	17	1	1	6	8	1	---	14	1	---	---	---	1	---	---
Aug. 1	21	1	2	10	6	1	1	15	2	---	1	---	---	---	1
2	17	---	---	7	3	6	1	16	1	---	---	1	---	---	---
3	6	---	---	2	4	---	---	19	1	---	---	---	1	---	---
4	9	---	---	4	4	1	---	20	3	---	---	1	1	1	---
5	12	---	1	5	4	2	---	23	1	---	---	---	1	---	---
6	9	---	1	5	3	---	---	Pupæ....	160	5	19	52	60	20	4
7	13	---	---	3	9	1	---								
8	10	---	1	1	4	3	1								

Days.

Average length of pupal stage.....	13.51
Maximum length of pupal stage.....	16
Minimum length of pupal stage.....	11

MOTHS OF THE SECOND BROOD.

Time of emergence.—The time of emergence of 170 moths of the second brood is presented in Table LI. The first of these moths issued August 7, the last about one month later on September 6. The period of greatest emergence occurred from August 14 to August 21. As has already been referred to (p. 59), there is an overlapping of moths of the first and second broods from August 7, the time when the first moths of the second brood appeared, to August 19, when the last of the first brood of moths emerged. In figure 28 will be found a graph illustrating the time of emergence with average daily temperatures.



FIG. 28.—Time of emergence of codling moths of the second brood, Grand Junction, Colo., 1916.

moths of the second brood appeared, to August 19, when the last of the first brood of moths emerged. In figure 28 will be found a graph illustrating the time of emergence with average daily temperatures.

TABLE LI.—*Time of emergence of codling moths of the second brood, from material reared at the insectary, Grand Junction, Colo., 1916.*

Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.	Date of emergence.	Number of moths.
Aug. 7	1	Aug. 14	18	Aug. 20	11	Aug. 26	3	Sept. 3	1
9	2	15	14	21	10	27	2	4	1
10	5	16	7	22	9	28	1	6	1
11	10	17	16	23	6	29	1		
12	5	18	13	24	7	31	1	Total..	170
13	8	19	11	25	4	Sept. 2	2		

Number of eggs per female moth.—Included in this study were 86 female moths which were confined with 78 males in four cages. As will be noted in Table LII, 3,920 eggs were deposited, or 45.58 eggs per female moth.

Time of oviposition.—Since only a comparatively small number of moths of the second brood emerged each day, the maximum never exceeding 16, it was thought best, for purposes of uniform manipulation, to confine moths of several days' emergence in the same cage, as shown in Table LII. It was therefore impossible to obtain accurately the length of life of these moths and the period before, of, and after oviposition. It will be noted, however, by reference to this table and Table LIV, that the first oviposition by these moths occurred August 12, three days after the first female moth emerged. The last female died September 28, 7 days after the last egg was deposited.

TABLE LII.—*Oviposition by codling moths of the second brood in rearing cages, Grand Junction, Colo., 1916.*

Cage No.	Number of moths.	Date of emergence of moths.	Sex of moths.		Total number of eggs deposited.	Cage No.	Number of moths.	Date of emergence of moths.	Sex of moths.		Total number of eggs deposited.	
			Male.	Female.					Male.	Female.		
1	1	Aug. 7	20	25	1,631	4	9	Aug. 22	21	18	571	
	2	Aug. 9					6	Aug. 23				
	5	Aug. 10					7	Aug. 24				
	9	Aug. 11					4	Aug. 25				
	5	Aug. 12					3	Aug. 26				
	7	Aug. 13					2	Aug. 27				
	16	Aug. 14					1	Aug. 28				
2	14	Aug. 15	26	23	1,627		1	Aug. 29				
	6	Aug. 16					1	Aug. 31				
	16	Aug. 17					2	Sept. 2				
	13	Aug. 18					1	Sept. 3				
3	11	Aug. 19	11	20	91		1	Sept. 4				
	10	Aug. 20					1	Sept. 6				
	10	Aug. 21										
Total...							164		78	86	3,920	

Average number of eggs per female, 45.58.

Length of life of moths.—As noted in the preceding paragraph, it was impossible to obtain accurate data on the length of life of the moths of the second brood, since the moths of several days' emergence

were confined in the same cage. However, one moth, a male, lived until September 30, 24 days after the last moth emerged. The last female died September 28, 22 days after the last moth emerged.

LIFE CYCLE OF THE SECOND GENERATION.

The data on the life cycle of the second generation, as given in Table LIII, include 161 individuals. The summary of the records gives an average for the incubation period of 6.01 days, larval feeding period 18.08 days, cocooning period 4.78 days, pupal period 13.52 days, and life cycle 42.40 days. To determine the length of the complete life cycle of this generation for 1916, approximately 3 days should be added to these figures, since as noted in a previous paragraph headed "Time of oviposition," 3 days elapsed between the date of emergence of the first female moth and the date the first egg was deposited.

TABLE LIII.—*Life cycle of the second generation of the codling moth, as observed by rearing, stock-jar feeding method, Grand Junction, Colo., 1916.*

Date of egg deposition.	Number of individuals.	Incubation.	Larval feeding period.			Cocooning period.			Pupal period.			Life cycle.		
			Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.
		Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
July 3	22	6	16.45	19	14	5.00	7	4	13.04	15	11	40.50	46	35
4	20	6	17.00	21	14	4.60	6	3	13.25	16	11	40.85	46	36
5	24	6	19.00	24	15	4.79	6	4	14.12	16	12	43.91	50	37
6	34	6	17.85	25	14	4.35	7	3	13.38	16	11	41.58	51	36
7	12	6	18.16	23	15	4.58	6	3	13.50	15	12	42.25	49	36
8	17	6	18.64	21	15	4.64	8	3	13.29	15	12	42.58	48	36
9	7	6	18.00	21	15	5.85	14	3	13.57	14	13	43.42	51	37
10	9	6	18.44	20	16	4.00	5	2	13.77	15	13	42.22	45	39
11	5	6	20.20	22	18	5.20	7	4	13.40	14	12	44.80	47	41
12	3	6	19.66	23	17	6.00	10	4	14.33	15	14	46.00	54	41
13	1	6	20.00	20	20	6.00	6	6	14.00	14	14	46.00	46	46
13	2	7	21.00	24	18	5.50	7	4	13.50	14	13	47.00	51	43
15	2	6	18.00	19	17	5.00	6	4	15.50	16	15	44.50	47	42
16	2	6	21.00	22	20	9.50	10	9	14.00	14	14	50.50	52	49
20	1	6	19.00	19	19	5.00	5	5	14.00	14	14	44.00	44	44
	161	6.01	18.08	25	14	4.78	14	2	13.52	16	11	42.40	54	35

THE THIRD GENERATION.

EGGS OF THE THIRD BROOD.

Time of deposition.—The moths of the second brood commenced to deposit third-brood eggs on August 12 and on September 10 laid the last egg that fully developed. One egg was laid much later, September 21, but this failed to reach maturity. The largest number of eggs laid in any one day, 223, was deposited on August 27. For further details of the time of oviposition see Table LIV and figure 29.

TABLE LIV.—*Time of deposition, length of incubation, and time of hatching of eggs of the third brood of the codling moth, Grand Junction, Colo., 1916.*

Observation No.	Number of eggs.	Date—				Appearance of—		Incubation period.
		Deposited.	Red ring.	Black spot.	Hatched.	Red ring.	Black spot.	
1	49	Aug. 12	Aug. 17	Aug. 19	Aug. 20	Days. 5	Days. 7	Days. 8
2	2	do	do	do	Aug. 21	do	do	9
3	3	Aug. 13	Aug. 15	Aug. 19	Aug. 20	2	6	7
4	31	do	do	do	Aug. 21	do	do	8
5	15	Aug. 14	Aug. 16	Aug. 20	do	2	6	7
6	138	do	do	do	Aug. 22	do	do	8
7	26	Aug. 15	Aug. 17	Aug. 21	do	2	6	7
8	117	do	do	do	Aug. 23	do	do	8
9	21	Aug. 16	Aug. 18	Aug. 22	do	2	6	7
10	82	do	do	do	Aug. 24	do	do	8
11	3	do	do	do	Aug. 25	do	do	9
12	34	Aug. 17	Aug. 19	Aug. 23	Aug. 24	2	6	7
13	6	do	do	do	Aug. 25	do	do	8
14	2	do	do	do	Aug. 26	do	do	9
15	89	Aug. 18	Aug. 20	Aug. 24	Aug. 25	2	6	7
16	68	do	do	do	Aug. 26	do	do	8
17	79	Aug. 19	Aug. 21	Aug. 25	do	2	6	7
18	77	do	do	do	Aug. 27	do	do	8
19	98	Aug. 20	Aug. 22	Aug. 26	do	2	6	7
20	82	do	do	do	Aug. 28	do	do	8
21	80	Aug. 21	Aug. 23	Aug. 27	do	2	6	7
22	16	do	do	do	Aug. 29	do	do	8
23	63	Aug. 22	Aug. 24	Aug. 28	do	2	6	7
24	27	do	do	do	Aug. 30	do	do	8
25	84	Aug. 23	Aug. 25	Aug. 29	Aug. 31	2	6	8
26	15	do	do	do	Sept. 1	do	do	9
27	68	Aug. 24	Aug. 26	Aug. 31	do	2	7	8
28	5	Aug. 25	Aug. 27	do	do	2	6	7
29	129	do	do	do	Sept. 2	do	do	8
30	16	do	do	do	Sept. 3	do	do	9
31	107	Aug. 26	Aug. 28	Sept. 2	do	2	7	8
32	7	do	do	do	Sept. 4	do	do	9
33	150	Aug. 27	Aug. 31	Sept. 3	do	4	7	8
34	71	do	do	do	Sept. 5	do	do	9
35	2	do	do	do	Sept. 6	do	do	10
36	31	Aug. 28	Aug. 31	Sept. 3	Sept. 4	3	6	7
37	2	do	do	do	Sept. 5	do	do	8
38	2	Aug. 29	Sept. 1	Sept. 4	do	3	6	7
39	51	do	do	do	Sept. 6	do	do	8
40	20	Aug. 30	Sept. 2	Sept. 5	do	3	6	7
41	7	do	do	do	Sept. 7	do	do	8
42	7	Aug. 31	Sept. 3	Sept. 6	do	3	6	7
43	11	do	do	do	Sept. 8	do	do	8
44	3	do	do	do	Sept. 10	do	do	10
45	3	Sept. 1	Sept. 4	Sept. 7	Sept. 8	3	6	7
46	5	do	do	do	Sept. 9	do	do	8
47	1	Sept. 3	do	Sept. 10	Sept. 11	do	7	8
48	1	do	do	do	Sept. 12	do	do	9
49	1	Sept. 4	do	Sept. 12	Sept. 14	do	8	10
50	*5	Sept. 5	do	do	do	do	do	do
51	*1	Sept. 7	do	do	do	do	do	do
52	1	Sept. 10	Sept. 12	Sept. 19	Sept. 21	2	9	11
53	*1	Sept. 21	do	do	do	do	do	do
Av.						2.49	6.36	7.77
Max.						5	9	11
Min.						2	6	7

* Eggs not included in averages, due to failure to develop fully.

Length of incubation.—The tabulated data of the embryological changes and length of the incubation of eggs of the third brood are given in Table LIV. From these data it was found that the average number of days from the date of deposition to the appearance of the red ring was 2.49 days, maximum 5 days, and minimum 2 days; the average number of days from the time of deposition

to the appearance of the black spot was 6.36 days, maximum 9 days, and minimum 6 days; the average incubation period was 7.77 days, maximum 11 days, and minimum 7 days.

LARVÆ OF THE THIRD BROOD.

Time of hatching.—

The larvæ of the third brood commenced to hatch August 20, as will be noted in Table LIV and figure 30. Hatching continued daily, with some exceptions, up to September 21, the period thus having a duration of about one month. The larvæ were hatching in maximum numbers on September 4, and on this date 188 hatched. A large proportion of the eggs, however, hatched previous to this,

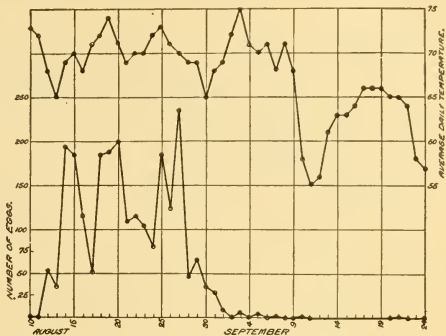


FIG. 29.—Time of deposition of third-brood eggs of the codling moth, Grand Junction, Colo., 1916.



FIG. 30.—Time of hatching of third-brood eggs of the codling moth, Grand Junction, Colo., 1916.

entered the fruit after September 11 reached maturity. It will be noted in Table LV that the average feeding period of the larvæ under observation was 37.55 days, maximum 68 days, and minimum 20 days.

namely from August 22 to 29.

Length of the feeding period.—The study of the feeding period of larvæ of the third brood, stock-jar method, included 331 larvæ. The first larvæ to hatch entered the fruit August 20, while the last larvæ entered the fruit September 21. None of the larvæ that entered

TABLE LV.—Length of feeding period of codling moth larvæ of the third brood, stock-jar method, Grand Junction, Colo., 1916.

Date of entering fruit.	Number of individuals.	Length of feeding period in specified days.																			
		20	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Aug.	20	27	3	1					3	1		7		1		1	2	1	2	1	
	21	16		1	2	2	3		1		3		1			1					
	22	23		1		2	1		1		5	1	1							2	
	23	16								3	1	2		1	1	2		1			2
	24	9						2	2	1	2			3							
	25	17					1	2		1	1	2	1	1	2	1	1				
	26	23			1			1				1	1	1			3	3			1
	27	19					2		1	1		2	1	1		1	3				1
	28	16									1	2	1			2	1		1	2	1
	29	18					1					2			1	1	1	4		1	
	30	13											1	1				2	2		
	Sept.	29	29				2		1			1	1	4		2	3	1	1	3	4
1	23						1				1	1	1	1	1	5	1	1	4		
2	27									1	3	1	2	1		3	3	2	2		
3	17									2				1		2	1		2	1	
4	9														1						
5	3																				1
6	14															1				2	2
7	8																			2	4
8	3																				
11	1																				
Larvæ..	331	3	3	3	4	5	6	7	10	17	14	18	16	11	11	19	25	12	16	16	12

Date of entering fruit.	Number of individuals.	Length of feeding period in specified days.																			
		41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	58	59	63	67	68
Aug. 20	27						1	1		1				1							
21	16										1										
22	23					2		1	2	2					1						
23	16		1	1	1																
24	9	1																			
25	17		1				1														
26	23	2	1				1	3			1			1	1				1		
27	19			1					2		1										
28	16	1			1		2	2													
29	18		1		1						1									1	
30	13			1	1				2					1				1	1	1	
31	29	2					1								1			1	1	1	
Sept. 1	23			2	1		1											1	1		
2	27	1		1	2		1				2		1			2	1				
3	17				1		1	2													
4	9	2			1				1						1	1					
5	3	1									1				1						
6	14	1				3					1	1				1		2			
7	8										1				1						
8	3					1				1					1						
11	1														1				1		
Larvæ..	331	11	4	6	9	14	10	6	3	5	7	1	1	3	7	4	1	5	1	3	2

Days.

Average length of feeding period..... 37.55
 Maximum length of feeding period..... 68
 Minimum length of feeding period..... 20

CODLING MOTH BAND STUDIES OF 1916.

The same orchards, the Edwards and Hamilton, that were used in the band studies in 1915 were again made use of in 1916. As in 1915, the larvæ were collected every three days from beneath burlap bands that encircled the trunks of certain trees and were kept under conditions identical with those that obtained the previous season.

The data from the studies of the larvæ collected in the Edwards orchard are given in Table LVI, in which it will be found that 50

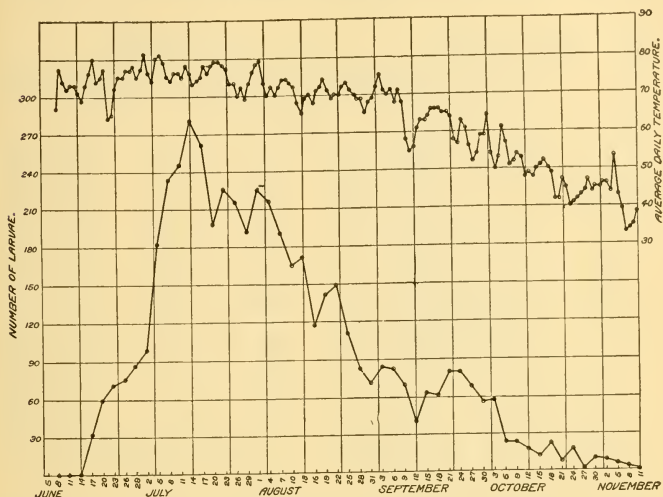


FIG. 31.—Number of codling moth larvæ collected from banded trees, Edwards orchard, Grand Junction, Colo., 1916.

collections were made beginning June 17 and ending November 11. During this period 4,998 larvæ were collected. Figure 31 represents the rate at which the larvæ were leaving the fruit during the three-day intervals throughout the season. It will be noted in the table that 49.19 per cent of the larvæ transformed to the adult stage in 1916, and that the remainder, 50.81 per cent, were wintering individuals. None of the larvæ collected in this orchard after August 19 transformed until the spring of the following year. The percentage of moths emerging in 1916 from each collection is shown diagrammatically in figure 32.

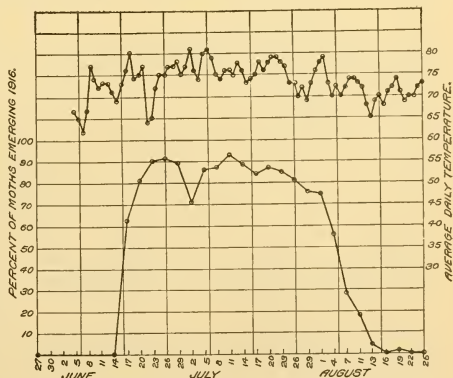


FIG. 32.—Percentage of codling moths emerging from band-collected material, Edwards orchard, Grand Junction, Colo., 1916.

TABLE LVI.—*Band-record experiment.—Codling moth larvæ collected at the Edwards orchard, Grand Junction, Colo., 1916.*

Date of collection, 1916.	Collection No.	Number of larvæ collected	Total number of moths emerging, 1916.	Per cent of—		Date of collection, 1916.	Collection No.	Number of larvæ collected.	Total number of moths emerging, 1916.	Per cent of—	
				Moths emerging, 1916.	Individuals wintering.					Moths emerging, 1916.	Individuals wintering.
June 17	1	32	20	62.50	37.50	Sept. 3	27	84	0	0.00	100.00
20	2	59	48	81.35	18.65	6	28	82	0	0.00	100.00
23	3	71	64	90.14	9.86	9	29	69	0	0.00	100.00
26	4	76	69	90.78	9.22	12	30	40	0	0.00	100.00
29	5	86	69	89.23	19.77	15	31	64	0	0.00	100.00
July 2	6	98	70	71.42	25.58	18	32	62	0	0.00	100.00
5	7	182	157	86.26	13.47	21	33	80	0	0.00	100.00
8	8	233	202	86.69	13.31	24	34	80	0	0.00	100.00
11	9	245	228	93.06	6.94	27	35	68	0	0.00	100.00
14	10	280	246	87.85	12.15	30	36	56	0	0.00	100.00
17	11	261	219	83.90	16.10	Oct. 3	37	58	0	0.00	100.00
20	12	198	172	86.86	13.14	6	38	24	0	0.00	100.00
23	13	226	192	84.95	15.05	9	39	24	0	0.00	100.00
26	14	215	175	81.39	18.61	12	40	18	0	0.00	100.00
29	15	192	146	76.04	23.96	15	41	13	0	0.00	100.00
Aug. 1	16	225	169	75.11	24.89	18	42	23	0	0.00	100.00
4	17	216	121	56.01	43.99	21	43	8	0	0.00	100.00
7	18	190	54	28.42	71.58	24	44	18	0	0.00	100.00
10	19	165	30	18.18	81.82	27	45	2	0	0.00	100.00
13	20	171	6	3.50	96.50	30	46	10	0	0.00	100.00
16	21	117	0	0.00	100.00	Nov. 2	47	9	0	0.00	100.00
19	22	142	2	1.40	98.60	5	48	6	0	0.00	100.00
22	23	149	0	0.00	100.00	8	49	4	0	0.00	100.00
25	24	111	0	0.00	100.00	11	50	2	0	0.00	100.00
28	25	83	0	0.00	100.00						
31	26	71	0	0.00	100.00						
						Total..					
						4,998					
						2,459					
						49.19					
						50.81					

In the Hamilton orchard 46 collections of larvæ were made, beginning on June 17 and ending October 30, following the harvest of the fruit. A total of 5,716 larvæ was collected as will be seen by reference to Table LVII. Of this number 33.60 per cent transformed to the imago in 1916 and 66.40 per cent wintered. The percentage of transforming larvæ from each collection in 1916 is shown in the graph, figure 33. No larvæ transformed in 1916 from any collection made in this orchard

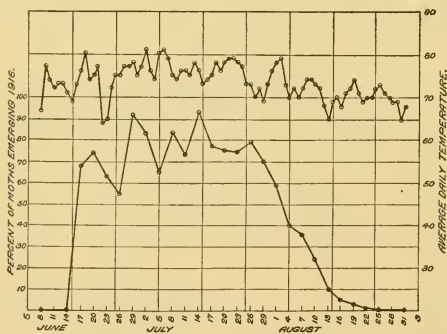


FIG. 33.—Percentage of codling moths emerging from band-collected material, Hamilton orchard, Grand Junction, Colo., 1916.

after August 22. Figure 34 represents the number of larvæ collected from banded trees at each interval.

In figure 35 the graph is intended to show the average daily temperatures and the number of first and second brood moths that

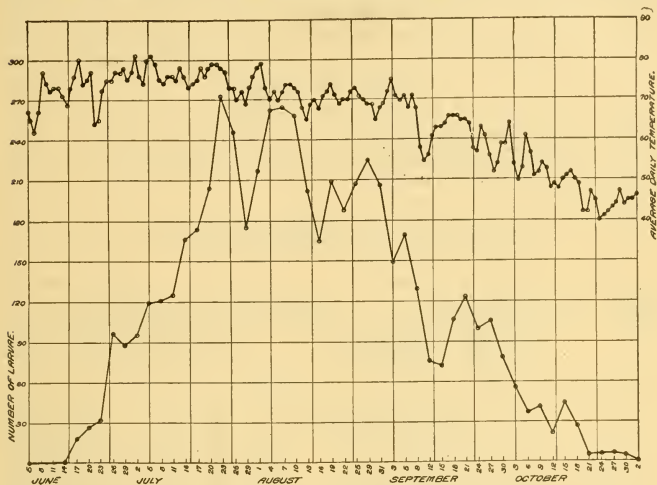


FIG. 34.—Number of codling moth larvae collected from banded trees, Hamilton orchard, Grand Junction, Colo., 1916.

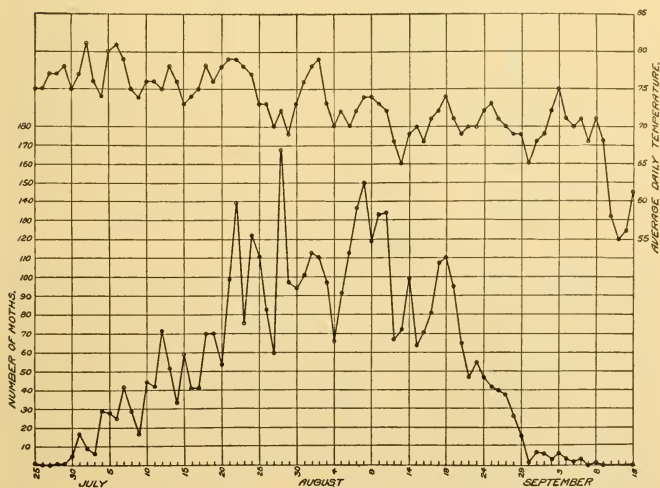


FIG. 35.—Time of emergence of codling moths from band-collected material, Hamilton and Edwards orchards, Grand Junction, Colo., 1916.

emerged from the larvæ collected from the banded trees at both the Edwards and Hamilton orchards. The first moth emerged June 25, the last September 8, a period of about two and a half months. The highest number of moths that issued in one day from this combined material was 167 on July 28, and this day was almost midway between the date of the first and last emergence. It will be recalled that, according to the insectary bred material, there was an overlapping of the first and second brood moths from August 7 to August 19 and that August 13 was theoretically considered as the dividing line between the two broods.

TABLE LVII.—*Band-record experiment, codling moth larvæ collected at the Hamilton orchard, Grand Junction, Colo., 1916.*

Date of collection, 1916.	Collection No.	Number of larvæ collected	Total number of moths emerging, 1916.	Per cent of—		Date of collection, 1916.	Collection No.	Number of larvæ collected.	Total number of moths emerging, 1916.	Per cent of—	
				Moths emerging, 1916.	Individuals wintering.					Moths emerging, 1916.	Individuals wintering.
June 17	1	19	13	68.42	31.58	Aug. 28	25	225	0	0.00	100.00
20	2	27	20	74.07	25.93	31	26	206	0	0.00	100.00
23	3	32	20	62.50	37.50	Sept. 3	27	149	0	0.00	100.00
26	4	96	53	55.20	44.80	6	28	169	0	0.00	100.00
29	5	88	81	92.04	7.96	9	29	129	0	0.00	100.00
July 2	6	95	79	83.15	16.85	12	30	76	0	0.00	100.00
5	7	119	77	64.70	35.30	15	31	72	0	0.00	100.00
8	8	121	100	82.64	17.36	18	32	106	0	0.00	100.00
11	9	125	91	72.80	27.20	21	33	123	0	0.00	100.00
14	10	165	154	93.33	6.67	24	34	99	0	0.00	100.00
17	11	173	134	77.45	22.55	27	35	105	0	0.00	100.00
20	12	204	153	75.00	25.00	30	36	78	0	0.00	100.00
23	13	272	201	73.89	26.11	Oct. 3	37	56	0	0.00	100.00
26	14	246	194	78.86	21.14	6	38	37	0	0.00	100.00
29	15	175	122	69.71	30.29	9	39	41	0	0.00	100.00
Aug. 1	16	217	128	58.98	41.02	12	40	22	0	0.00	100.00
4	17	262	106	40.45	59.55	15	41	44	0	0.00	100.00
7	18	264	94	35.60	64.40	18	42	27	0	0.00	100.00
10	19	258	63	24.41	75.59	21	43	6	0	0.00	100.00
13	20	202	21	10.39	89.61	24	44	6	0	0.00	100.00
16	21	164	8	4.87	95.13	27	45	7	0	0.00	100.00
19	22	209	6	2.87	97.13	30	46	5	0	0.00	100.00
22	23	¹ 188	1	² 0.54	² 99.46						
25	24	207	0	0.00	100.00		Total..	5,716	1,919	² 33.60	² 66.40

¹ 5 larvæ killed in handling.

² All percentages based upon number of live larvæ collected.

NATURAL ENEMIES OF THE CODLING MOTH.

PREDACIOUS ENEMIES.

The codling moth in the Grand Valley is seldom attacked by predacious insects and, as a result, the reduction of the pest by this means is quite inconsequential. A small beetle, *Tenebroides corticalis* Melsh., which, in its larval and adult stages, is known to feed upon the codling moth larva, was occasionally taken from beneath the bands on apple trees. A spider, *Coriarachne versicolor* Keys., was found from time to time feeding upon larvæ of the codling moth. This spider is a general feeder and is commonly found beneath the loose bark of orchard and shade trees.

In view of the comparative absence of predacious insect enemies an attempt was made to introduce the well-known beetle *Calosoma*

sycophanta L., which has been instrumental in partially reducing the number of brown-tail moth and gipsy moth larvæ as well as other lepidopterous larvæ of the New England States. Over 1,000 of these beetles were released in June, 1915, but none were recovered after their distribution.

PARASITIC ENEMIES.

The parasitic enemies of the codling moth in the Grand Valley play a very unimportant rôle in its control, although in one instance an egg parasite, *Trichogramma minutum* Riley, was found quite abundant in the field in a small pear orchard. Some of the foliage surrounding the fruit was pulled at random and then was examined for eggs. Out of the first 100 eggs found, 15 were parasitized by this insect. As many as three of these parasites were found developing within one codling moth egg, while quite frequently two of the parasites inhabited the same egg.

Another parasite, *Dibrachys clisiocampae* Fitch, was found to attack the codling-moth larva and continue to feed upon the host after it had transformed to the pupa stage.

The parasite *Arthrolytus apatellae* Ashmead was also reared from material collected in the field.

In general, the occurrence of parasitism was so infrequent that little good was accomplished by this class of natural enemies.

MISCELLANEOUS STUDIES.

EFFECT OF COOL TEMPERATURES ON EMERGENCE OF MOTHS OF THE SPRING BROOD.

In laboratory cellar.—As a means of studying the influence of cool temperatures upon the emergence of moths of the spring brood, a number of wintering larvæ were placed in the cellar of the laboratory. This cellar was of the usual type, having stone walls and a cement floor, and was moderately dry. The temperature and atmospheric conditions within would compare somewhat with the fruit cellars or caves in which fruit is sometimes stored in the Grand Valley. The cage containing the insects was examined daily and the results of the observations will be found in Table LVIII.

A study of this table will show that the first moth, under cellar conditions, did not emerge until May 30, or 18 days after the first adult appeared in the outdoor insectary. It is noteworthy that the last emergence of moths in the cellar cage and the insectary cages occurred the same day, June 29. From these observations it would appear that the lower temperature in the cellar had a retarding influence in the development of the insect for some time, but that after the insects had been subjected to a sufficient accumulation of effective temperatures, their complete transformations to the adult stage were not long delayed.

TABLE LVIII.—*Emergence of codling moths of the spring brood, laboratory cellar, Grand Junction, Colo., 1915.*

Date of observation and collection.	Number of moths.	Date of observation and collection.	Number of moths.	Date of observation and collection.	Number of moths.	Date of observation and collection.	Number of moths.	Date of observation and collection.	Number of moths.
May 30	1	June 10	3	June 15	6	June 20	9	June 27	2
31	2	11	6	16	15	21	2	28	3
June 6	4	12	3	17	7	22	2	29	2
7	1	13	1	18	13	23	1		
8	3	14	2	19	8	26	4	Total.	105
9	5								

In fruit cellar.—Observations were also taken of the time of emergence of moths of the spring brood in a fruit cellar beneath a large packing house where considerable wormy fruit had been temporarily stored the previous fall. The records are from moths secured from a cage containing wintering larvæ and also from moths captured at a screened window. The observations were made only on the dates recorded in Table LIX. In this table it will be seen that 105 moths emerged in the cage, while 48 were captured at the window. In the latter connection it should be borne in mind that the records of the insects found at the window do not necessarily indicate the true time of their emergence. The emergence period of the caged insects in the fruit cellar was somewhat similar to that in the laboratory cellar.

It will be observed from the foregoing that moths may be expected to emerge from fruit cellars later than those out-of-doors, and this emergence augments, to a certain extent, the late injury as caused by the first brood of larvæ.

TABLE LIX.—*Emergence of codling moths of the spring brood, cellar of fruit packing house, Grand Junction, Colo., 1915.*

Date of observation and collection.	Number of moths—		Date of observation and collection.	Number of moths—		Date of observation and collection.	Number of moths—	
	In cage.	Found at screened window.		In cage.	Found at screened window.		In cage.	Found at screened window.
June 2	1	0	June 19	5	2	July 3	0	2
8	21	0	21	6	16	7	1	8
12	32	0	23	3	3	26	0	1
15	26	0	24	1	4			
16	7	1	29	2	11	Total	105	48

TIME OF DAY MOTHS EMERGE.

During the seasons of 1915 and 1916 observations were made to obtain data relative to the time of day the moths of the spring and first broods emerged in largest numbers. These studies are reported herewith.

Moths of the spring brood, 1915.—A certain lot of wintering larvæ were placed in cages with the view to determining at what periods of the day the moths of the spring brood emerge. The observations were taken at 8 a. m., noon, and 6 p. m. from May 14 to May 28, inclusive. It will be noted in Table LX that 1,189 moths issued during the 15-day period; 60, or 5.05 per cent, issued between 6 p. m. and 8 a. m.; 928, or 78.05 per cent, between 8 a. m. and 12 o'clock noon, and 201 moths, or 16.90 per cent, between 12 noon and 6 p. m.

TABLE LX.—*Emergence of codling moths of the spring brood, Grand Junction, Colo., 1915.*

Date of observation.	Number of moths emerging—			Date of observation.	Number of moths emerging—		
	6 p. m. to 8 a. m.	8 a. m. to 12 noon.	12 noon to 6 p. m.		6 p. m. to 8 a. m.	8 a. m. to 12 noon.	12 noon to 6 p. m.
May 14	0	0	19	May 23	0	104	20
15	9	23	13	24	5	175	17
16	0	114	12	25	9	109	0
17	34	98	16	26	0	25	22
18	0	21	8	27	0	75	29
19	1	28	0	28	1	75	24
20	1	0	0				
21	0	3	5	Total..	60	928	201
22	0	78	16	Per ct..	5.05	78.05	16.90

Moths of the first brood, 1915.—Records of the emergence of moths of the first brood were taken hourly from 6 a. m. to 6 p. m., inclusive, and again at 9 p. m. and 12 o'clock midnight from August 16 to 20, inclusive. A total of 641 moths was used in this study, the details of which are given in Table LXI, in which it will be observed that no moths issued between midnight and 6 a. m., nor did any emerge between 6 a. m. and 7 a. m. During the 5-hour interval from 9 a. m. to 2 p. m., 431 moths, or 67.24 per cent, issued. The maximum emergence for any one hour occurred during the period from 9 a. m. to 10 a. m. From 6 p. m. to 7 a. m., a period of 13 hours, there emerged 35 moths, or 5.46 per cent of the total.

TABLE LXI.—*Emergence of codling moths of the first brood, hourly, from 6 a. m. to 6 p. m., and at 9 p. m. and 12 midnight, Grand Junction, Colo., 1915.*

Date of emergence of moths.	Observation No.	Number of moths emerging at—														Total number of moths.	
		A. M.							P. M.								
		6	7	8	9	10	11	12	1	2	3	4	5	6	9		12
Aug. 16	1	.....	.....	.....	.....	3	14	2	6	4	7	5	3	1	5	.....	50
17	2	.....	.....	.....	.....	48	36	18	3	8	2	7	12	8	10	.....	152
18	3	.....	.....	.....	16	24	25	11	12	11	10	14	12	1	6	1	143
19	4	.....	.....	1	9	34	22	20	25	12	8	8	10	9	3	.....	161
20	5	.....	.....	1	1	25	21	16	18	13	13	8	6	3	8	2	135
Total.	.....	0	0	2	26	134	118	67	64	48	40	42	43	22	32	3	641

Moths of the spring brood, 1916.—Observations of the time of emergence of moths of the spring brood were made hourly from 7 a. m. to 6 p. m. from May 17 to 31, inclusive, as recorded in Table LXII. It will be noted therein that the largest number of moths issued between 12 o'clock noon and 1 p. m. The heaviest emergence period was the five-hour interval from 9 a. m. to 2 p. m., during which 895 moths, or 67.14 per cent of the total number of 1,333 moths, issued. Only 40 moths, or 3 per cent of the total, emerged during the period of 13 hours from 6 p. m. until 7 a. m.

TABLE LXII.—*Emergence of codling moths of the spring brood, hourly, from 7 a. m. to 6 p. m., Grand Junction, Colo., 1916.*

Date of emergence of moths.	Ob- serva- tion No.	Number of moths emerging at—												Total num- ber of moths.
		A. M.						P. M.						
		7	8	9	10	11	12	1	2	3	4	5	6	
May 17	1						10	34	5	2	2			53
18	2	1			1	30	19	9	4	6				70
19	3		4	4	27	27	27	15	18	5	3		1	131
20	4													.0
21	5									7	2	2		11
22	6		1		7	21	40	49	19	12	2	5	1	157
23	7					29	50	32	17	14	5	2		149
24	8	37	29	55	34	25	8	13	15	6	10	7	6	245
25	9	1	1					17	25	15	1	1	1	62
26	10							15	20	3	2			40
27	11						3	24	11	8	3	1		50
28	12					50	24	18	7	6	3	1		169
29	13				2	21	15	19	19	10	5			91
30	14	1		2	40	23	14	13	5	3	4	5		110
31	15				12	12	8	8	8	2	1	3	1	55
Total.	.....	40	35	61	123	238	218	266	173	92	48	27	12	1,333

¹ About 5 of these moths found at 7 a. m. were spreading their wings, having emerged between 6 and 7 a. m.

Moths of the first brood, 1916.—A study of the time of emergence of first-brood moths was begun July 17 and ended August 4, and during this time observations were taken hourly from 6 a. m. to 6 p. m. The record of the observations shows that a total of 1,761 moths emerged, as is given in Table LXIII. The maximum emergence for a 1-hour period was 213 moths, which issued from 9 to 10 a. m. During the 5-hour period from 9 a. m. to 2 p. m. 923 issued, or 52.41 per cent of the total number of moths emerging. For the 13-hour period from 6 p. m. to 7 a. m. 61 moths, or 3.46 per cent, emerged.

From the foregoing studies it will be noted that the majority of the moths of the spring and first broods emerged during the latter part of the morning and early part of the afternoon, with the maximum emergence usually occurring from 9 to 11 a. m. During the 5-hour period from 9 a. m. to 2 p. m. from 52 to 67 per cent of the moths emerged; whereas during the 13-hour interval from 6 p. m. to 7 a. m. only from 3 to 5 per cent issued.

TABLE LXIII.—*Emergence of codling moths of the first brood, hourly, from 6 a. m. to 6 p. m., Grand Junction, Colo., 1916.*

Date of emergence of moths.	Observation No.	Number of moths emerging at—														Total number of moths.
		A. M.							P. M.							
		6	7	8	9	10	11	12	1	2	3	4	5	6		
July 17	1	---	---	---	3	6	6	5	1	5	2	4	6	3	41	
18	2	---	---	1	---	11	13	11	7	9	6	3	5	3	69	
19	3	1	---	1	4	7	9	12	4	8	4	11	7	3	71	
20	4	---	2	1	1	1	5	2	7	8	1	12	5	8	53	
21	5	1	3	1	9	13	9	8	11	12	13	10	5	1	96	
22	6	4	---	---	8	20	32	21	12	9	16	10	5	4	141	
23	7	2	2	2	8	25	15	5	5	4	1	2	2	3	76	
24	8	---	---	---	1	---	5	12	16	10	22	15	32	6	119	
25	9	3	1	---	4	10	18	16	6	---	9	11	25	8	111	
26	10	3	1	---	2	3	4	1	5	6	4	18	21	9	77	
27	11	9	1	5	8	6	4	2	4	11	12	6	---	---	68	
28	12	1	---	---	19	26	6	4	9	16	35	30	18	3	167	
29	13	1	1	---	2	5	7	8	16	15	8	13	11	7	94	
30	14	4	2	---	4	26	20	1	3	4	3	7	10	7	91	
31	15	7	---	---	8	12	4	2	20	16	13	10	5	6	103	
Aug. 1	16	5	---	1	12	20	16	15	18	10	1	6	11	2	117	
2	17	1	3	---	10	11	27	25	9	7	8	5	4	---	110	
3	18	1	1	3	7	4	5	9	22	13	8	13	9	2	97	
4	19	1	---	---	4	7	1	2	3	2	11	3	9	17	60	
Total ..	-----	44	17	15	114	213	206	161	178	165	177	189	190	92	1,761	

CODLING-MOTH FLIGHT TRIALS.

In connection with the habits of the codling moth, the question, "How far does the codling moth fly?" has frequently been asked, but it has not been possible to answer this query definitely on account of the lack of satisfactory data. It is generally conceded by the fruit growers of the Grand Valley that the codling moth migrates to a certain extent. They have observed that the outside rows of their orchards frequently have a greater percentage of wormy fruit, which they attribute to the immigration of moths from near-by orchards. It has also been found that the fruit on trees in the vicinity of the packing houses is, as a rule, quite wormy, due to the migration of the moths from the packing houses.

According to the observations of the writers, it is believed that the codling moth does not migrate long distances in a continuous flight, but by means of short flights may proceed from one tree to the next or fly across a road from one orchard to the adjoining or from the packing house to the neighboring trees, or occasionally fly a few hundred feet from one orchard to another. The normal flight, however, is restricted, as may be noted about dusk, when the moths are most active and may be seen flitting about in a tree or flying from one tree to another near by.

Perhaps the strongest evidence that the moths do not migrate in large numbers to any considerable extent was noted in 1915, when only a few smudged orchards, outside of the Palisade district, had a fruit crop. While the apples in these protected orchards were quite

wormy, it is believed that had there been a large influx of moths from the hundreds of acres of surrounding orchards in which there was no fruit, it would have been practically impossible to have saved the crop with the normal spraying schedule.

In order to determine how far the adults can actually fly, it was thought desirable to make some moth-flight tests. Accordingly, trials were made on the mornings of June 11, 17, 24, July 27, 29, and August 3, 1915. These tests were usually made early in the morning and, in so far as possible, when the atmosphere was quiet and the temperature moderately low in order that the moths would fly at a slow speed. When the wind is moderate to strong or the temperature high, the moths are very rapid in their flight, so that it is impossible to follow them.

The moths were released one at a time from a central point, and Mr. Van Leeuwen and the senior author followed their course on foot. In all, several hundred moths were released and out of this number it was possible to secure data on a few. In many instances the moths ascended high into the air and were lost from view, in other instances they dropped into bushes, while in some cases their flight was either too erratic or swift to follow. The flight of the male moths was generally much more irregular and speedy than that of the other sex.

In determining the distance covered, measurements were made from the starting point to the place where the moths dropped or were lost from view. It should be noted, however, that the actual distance between the starting and finishing points, as measured by pacing, was usually only a small part of the distance the moths flew, since they seldom went in a straight line and it was impossible to take into account the numerous deviations from a direct course. Nevertheless, an attempt was made to estimate the number of feet actually traveled during the flight whenever the moths proceeded in a new direction for a considerable distance. This was done by counting the steps of the observers and allowing a certain distance per step. In this connection it should be borne in mind that the estimated distances, although approximate, are conservative.

In Table LXIV the flight records of 35 moths are given. Three of these covered a distance of over a thousand feet in one flight, measuring from the point of release to the place where the moths disappeared from view or dropped to the ground. The maximum air-line distance of 1,344 feet was made by a male moth. One female moth that flew, in $6\frac{1}{2}$ minutes, a distance of 1,035 feet measured in a straight line, traveled an estimated distance of 3,000 feet and was still flying when it disappeared from sight. Another female moth, after flying continuously for $7\frac{1}{2}$ minutes, was lost from view.

It would seem from the foregoing that the codling moth is capable of making a fairly long and sustained flight, but it does not neces-

sarily follow from this that the moth naturally migrates to any considerable extent.

TABLE LXIV.—*Flight records of the codling moth, Grand Junction, Colo., 1915.*

Moth No.	Sex of moth.	Date of flight.	Actual distance between starting and finishing points.	Estimated distance of flight between starting and finishing points.	Remarks.
			<i>Fect.</i>	<i>Fect.</i>	
1	.....	June 11	165	.....	In two flights.
2	Male	do.	120	.....	Lost from view.
3	do.	do.	360	720	Dropped to ground; when released, flew from sight.
4	do.	do.	138	.....	On wing 2 minutes, then lost from view.
5	Female	do.	189	.....	Do.
6	do.	do.	840	2,500	On wing 5 minutes, then lost from view.
7	do.	do.	600	1,800	On wing 7½ minutes, then lost from view.
8	do.	do.	420	1,200	In two flights, on wing 6½ minutes, then lost from view.
9	do.	do.	180	.....	Flew out of sight.
10	.....	June 17	390	600	On wing 3 minutes, then lost from view.
11	do.	do.	579	750	On wing 4 minutes, then lost from view.
12	Male	do.	249	.....	On wing 1 minute, then lost from view.
13	Female	June 24	715	.....	On wing 1½ minutes, then lost from view; swift flier.
14	do.	do.	294	.....	On wing 1½ minutes, then lost from view.
15	do.	do.	135	.....	Dropped to bushes.
16	do.	do.	276	.....	On wing 1½ minutes, dropped to bushes.
17	do.	do.	180	350	On wing 2 minutes, then lost from view.
18	do.	do.	717	1,000	On wing 2½ minutes, then lost from view.
19	Male	do.	507	.....	Very erratic; exhausted after 6-minute flight.
20	do.	July 27	102	.....	Dropped to bushes.
21	do.	do.	699	749	On wing 2 minutes.
22	Female	do.	1,035	3,000	On wing 6½ minutes, then lost from view
23	do.	do.	910	.....	Lost from view.
24	do.	do.	595	.....	On wing 2 minutes.
25	Male	do.	336	.....	On wing 1 minute.
26	do.	do.	150	.....	.....
27	Female	do.	1,155	.....	On wing 4 minutes, then lost from view
28	Male	do.	1,344	.....	.....
29	Female	July 29	117	.....	.....
30	Male	do.	590	.....	.....
31	Female	do.	792	.....	.....
32	do.	do.	1,356	.....	In two flights.
33	Female	Aug. 3	747	.....	Dropped to ground, apparently exhausted
34	Male	do.	789	.....	In two flights, on wing 2 minutes.
35	Female	do.	423	.....	In three flights, on wing 1¼ minutes.

TIME OF COPULATION.

Observations of the time of copulation of the codling moth were taken during the seasons of 1915 and 1916. (See Pl. I, B.) The data for 1916 are more extensive than those for the preceding year. No attempt was made to watch the moths closely at all times, but instead they were examined at intervals to note if they had separated.

In 1915 the following records were secured:

Moths of the spring brood.—May 30, one pair found in copula at 7 p. m.; June 8, one at 6.50 a. m.; June 9, one at 6.45 a. m., and another pair at 7 a. m.

Moths of the first brood.—The data for moths of this brood are presented in Table LXV.

The observations in 1916 of the copulatory period of moths are given in two tables: Table LXVI for moths of the spring brood and Table LXVII for moths of the first brood.

TABLE LXV.—*Observations of the copulatory period of codling moths of the first brood, Grand Junction, Colo., 1915.*

Pair No.	Date found in copula.	Time found in copula.	Moths separated.	Minimum time attached.	
				Hours.	Minutes.
1	Aug. 7	8.00 a. m.	After 10 a. m.	2	.....
2	..do.	8.45 a. m.	After 2.30 p. m.	5	45
3	Aug. 10	6.30 a. m.	After 9 a. m.	2	30
4	Aug. 14	8.40 a. m.	After 3 p. m.	6	20
5	Aug. 16	7.00 a. m.	Before 3 p. m.	.....	.....
6	..do.	9.30 p. m.	After 12.45 a. m. (Aug. 17)	3	15
7	..do.	9.50 p. m.	After 12 midnight	2	10
8	..do.	9.55 p. m.	Before 12 midnight	.....	.....
9	Aug. 18	9.05 a. m.	Before 1.30 p. m.	.....	.....
10	Aug. 19	2.45 a. m.	Before 6 a. m.	.....	.....
11	..do.	..do.	After 7.15 a. m.	4	30
12	..do.	9.15 p. m.	Before 12 midnight	.....	.....

TABLE LXVI.—*Observations of the copulatory period of codling moths of the spring brood, Grand Junction, Colo., 1916.*

Pair No.	Date moths emerged.	Date found in copula.	Time found in copula.	Moths separated subsequent to—	Minimum time attached.	
					Hours.	Minutes.
			<i>A. M.</i>			
1	.....	May 19	9.40	6.30 p. m.	8	50
2	May 16	May 25	10.30	6.06 p. m., May 26	31	36
3	May 19	May 30	10.50	1 p. m.	2	10
4	..do.	May 31	8.59	11.02 a. m.	2	3
5	May 22	..do.	7.59	3 p. m.	7	1
6	May 23	May 25	11.50	12 noon, May 27	48	10
7	..do.	May 30	10.23	10.55 a. m.	.....	32
8	..do.	May 31	7.45	9.37 a. m.	1	52
9	..do.	June 2	7.58	1.40 p. m.	5	42
10	..do.	June 3	7.12	2.15 p. m.	7	3
11	..do.	..do.	7.12	6.25 p. m.	11	13
12	..do.	..do.	7.14	6.25 p. m.	11	11
13	May 24	May 31	7.29	8.06 a. m.	.....	37
14	..do.	June 2	7.00	1.40 p. m.	6	40
15	..do.	..do.	7.15	5.48 p. m.	10	33
16	..do.	June 13	7.45	1.48 p. m.	6	3
17	May 27	June 4	6.45	3.07 p. m.	8	22
18	..do.	June 5	6.45	11.15 a. m.	4	30
19	May 28	June 2	6.45	7 a. m.	.....	15
20	May 29	..do.	6.25	5.48 p. m.	11	23
21	May 31	June 3	6.25	9.50 a. m.	3	25
22	June 3	June 20	7.25	1.30 p. m.	6	5
23	June 4	June 7	6.25	11 a. m.	4	35
24	..do.	June 9	6.35	2.30 p. m.	7	55
25	June 8	June 12	6.20	6.15 p. m.	11	55
26	June 11	June 13	6.15	6.15 p. m.	12	.....
27	June 15	June 21	6.45	3 p. m.	8	15
28	June 16	June 23	6.50	5.45 p. m.	10	55

TABLE LXVII.—*Observations of the copulatory period of codling moths of the first brood, Grand Junction, Colo., 1916.*

Pair No.	Date moths emerged.	Date found in copula.	Time found in copula.	Moths separated subsequent to—	Minimum time attached.	
					Hours.	Minutes.
			A. M.			
1	July 24	July 25	7.43.....	11.40 a. m.....	3	57
2	July 27	Aug. 2	7.20.....	4.50 p. m.....	9	30
3	July 28	July 31	7.13.....	12.15 p. m.....	5	2
4	do.	do.	7.19.....	12.15 p. m.....	4	56
5	Aug. 3	Aug. 5	6.54.....	2.37 p. m.....	7	43
6	do.	do.	9.52.....	6.00 p. m.....	8	8
7	Aug. 4	Aug. 11	7.29.....	5.48 p. m.....	10	19
8	Aug. 5	Aug. 7	7.00.....	4.55 p. m.....	9	55
8	do.	Aug. 8	7.05.....	12.19 p. m.....	5	14
9	Aug. 6	Aug. 13	6.20.....	10.09 a. m.....	3	49
10	do.	Aug. 20	7.45.....	10.00 p. m.....	14	15
11	Aug. 9	Aug. 12	7.06.....	2.45 p. m.....	7	39
12	Aug. 10	Aug. 15	7.25.....	12.10 p. m.....	4	45
13	Aug. 11	Aug. 13	6.00.....	10.40 a. m.....	4	40
14	Aug. 12	Aug. 23	7.45.....	8.02 a. m.....	.....	17
15	Aug. 14	Aug. 17	7.20.....	11.27 a. m.....	4	7
16	do.	Aug. 20	6.50.....	3.55 p. m.....	9	5
17	do.	Sept. 1	7.40.....	Died previous to separation.		
18	Aug. 28	do.	7.00.....	8.05 a. m.....	1	5

TIME OF DAY MOTHS OVIPOSIT.

A series of studies was inaugurated in 1915 and continued in 1916 to ascertain the time of day the moths deposit their eggs most freely. The results of these studies are given herewith.

Moths of the first brood, 1915.—This experiment included 11 cages in which were confined a number of male and female moths. The observations were made at 3 p. m., 6 p. m., 9 p. m., 12 o'clock midnight, 6 a. m., 9 a. m. and 12 o'clock noon, or, in other words, daily every 3 hours except at 3 a. m. These studies were commenced at 12 o'clock noon August 16 and were concluded at 6 a. m. August 21. At each examination the old foliage was removed and a fresh supply furnished, and at the same time the number of eggs deposited on the sides of the cages was recorded and the eggs removed. Some eggs were deposited on the sand in the bottom of the jars, but as these could not be accurately counted, they were not taken into consideration.

In Table LXVIII the tabulated data of the time of deposition of 3,621 eggs will be found in addition to the mean temperatures during the periods of observation. This table has been summarized and the data presented in Table LXIX, by reference to which it will be noted that the great majority of the eggs were deposited between 12 o'clock noon and 9 p. m. The time of greatest deposition occurred just before dusk, the moths being very active at this time. It is of interest to note that with a mean temperature of 78.90° F. during 5 observation periods from 9 a. m. till 12 o'clock noon, only 2.34 per cent of the eggs were laid, whereas the moths laid much more abundantly with both higher and lower mean temperatures when these occurred later in the day.

TABLE LXVIII.—Time of oviposition by codling moths of the first brood; observations taken daily every three hours, except at 3 a. m., Grand Junction, Colo., 1915.

Cage No.—		1	2	3	4	5	6	7	8	9	10	11	Number of eggs deposited on—										Number of eggs deposited on—		Total number of eggs deposited.	Mean temperature between observations.	
Moths emerged August—		10	10	10	11	11	12	12	13	13	13	13	Foliage.	Cage.	Foliage.	Cage.	Foliage.	Cage.	Foliage.	Cage.	Foliage.	Cage.	Foliage.	Cage.			
Date of observation.	Time of observation.	Aug. 16	12 m.	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	77.25	
		3 p. m.	28	15	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	213	79.00	
17	6 p. m.	64	27	41	0	33	10	18	2	37	1	30	8	0	0	0	0	0	0	0	0	0	0	0	300	75.25	
	9 p. m.	6	8	3	0	4	5	15	2	15	0	38	0	0	0	0	0	0	0	0	0	0	0	0	18	67.50	
18	12 m.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	60.25		
	3 p. m.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	55.00		
19	6 p. m.	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	66.50		
	9 a. m.	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	77.25		
20	12 m.	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	87.25	
	3 p. m.	11	21	16	1	33	10	36	2	12	2	45	3	0	0	0	0	0	0	0	0	0	0	0	17	87.00	
21	6 p. m.	28	25	9	3	33	13	46	0	37	7	38	0	0	0	0	0	0	0	0	0	0	0	0	141	74.25	
	9 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	63.00		
Total	12 m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	63.50	
	3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	57.43	
Total	6 p. m.	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	63.75	
	9 a. m.	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	79.00		
Total	12 m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	89.00	
	3 p. m.	3	2	5	1	7	2	8	4	1	53	0	7	0	0	0	0	0	0	0	0	0	0	0	27	88.00	
Total	6 p. m.	14	10	14	1	26	10	65	13	3	67	8	4	2	11	26	3	3	3	3	3	3	3	3	210	88.00	
	9 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	75.25	
Total	12 m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	66.75	
	3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	59.86	
Total	6 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	63.75	
	9 a. m.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	80.25	
Total	12 m.	2	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8	90.50	
	3 p. m.	2	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	89.75	
Total	6 p. m.	6	8	12	10	11	10	19	2	12	2	17	6	2	10	9	9	9	9	9	9	9	9	9	167	89.75	
	9 a. m.	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	241	77.25	
Total	12 m.	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	66.50	
	6 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	63.29	
Total		221	263	101	45	151	274	206	39	358	110	189	48	288	86	239	18	127	82	241	206	205	124	2,326	1,265	3,621	

n = noon; m t. = midnight.

TABLE LXIX.—*Time of oviposition by codling moths of the first brood; observations taken daily every three hours, except at 3 a. m.; Grand Junction, Colo., 1915; summary of Table LXVIII.*

Number of observation periods.	Period of observation.	Total number of eggs deposited.	Average number of eggs per oviposition period.	Per cent of eggs deposited per oviposition period.	Mean temperature during oviposition periods.
					° F.
5	12 mt. to 6 a. m....	7	1.40	0.19	59.00
4	6 a. m. to 9 a. m....	24	6.00	.83	64.56
5	9 a. m. to 12 m.	85	17.00	2.34	78.90
5	12 m. to 3 p. m.	598	119.60	16.49	87.15
5	3 p. m. to 6 p. m.	1,375	275.00	37.91	85.10
5	6 p. m. to 9 p. m.	1,492	298.40	41.14	73.70
5	9 p. m. to 12 mt.	40	8.00	1.10	64.00

m=noon; mt.=midnight.

Moths of the spring brood, 1916.—The study of the time of oviposition by moths of the spring brood was commenced at 12 o'clock noon on June 5 and the observations were made daily every 3 hours, except at 3 a. m., until 12 o'clock noon June 12, a period of one week. The details of this study are presented in Table LXX and summarized in Table LXXI. By reference to the latter it will be noted that over 79 per cent of the eggs were deposited from 3 p. m. to 9 p. m. It will be seen in the table that the mean temperature for the 7 days from 9 a. m to 12 o'clock noon was 76.39° F. Although this temperature is in no wise unfavorable for egg deposition, yet only 1.54 per cent of the eggs were deposited during this interval. Later in the day, with both higher and lower mean temperatures, much higher percentages of eggs were deposited. From 3 p. m. to 6 p. m. 58.80 per cent of the eggs were laid, the mean temperature being 82.92° F., or a little over 6° higher than the temperature from 9 a. m. to 12 o'clock noon. From 6 p. m. to 9 p. m., with a temperature of 73.14° F., 20.52 per cent of the eggs were deposited.

TABLE LXX.—Time of oviposition by codling moths of the spring brood. Observations taken daily every three hours except at 3 a. m., Grand Junction, Colo., 1916.

Cage No. —	1	2	3	4	5	6	7	8	9	10		Number of eggs deposited on—	Total number of eggs deposited.	Mean temperature, between
Date of observation.	23	23	23	23	23	23	23	23	24	24	24	Foliage.	Cage.	° F.
June 5	0	0	0	0	0	0	0	0	0	0	0	22	4	81.25
	15	0	0	0	0	0	0	0	0	0	0	37	3	78.75
	1	1	1	0	0	0	0	0	0	0	0	7	5	70.75
	0	0	0	0	0	0	0	0	0	0	0	0	2	63.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	53.71
June 6	0	0	0	0	0	0	0	0	0	0	0	0	0	56.75
	0	0	0	0	0	0	0	0	0	0	0	0	0	70.75
	0	0	0	0	0	0	0	0	0	0	0	20	2	78.50
	1	0	0	0	0	0	0	0	0	0	0	43	4	47.78.50
	19	3	0	0	0	0	0	0	0	0	0	11	0	68.50
June 7	0	0	0	0	0	0	0	0	0	0	0	0	0	60.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	49.14
	0	0	0	0	0	0	0	0	0	0	0	9	0	55.00
	0	0	0	0	0	0	0	0	0	0	0	9	0	68.25
	0	0	0	0	0	0	0	0	0	0	0	6	0	76.25
June 8	5	1	0	0	0	0	0	0	0	0	0	35	7	77.50
	0	0	0	0	0	0	0	0	0	0	0	1	5	68.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	56.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	49.28
	0	0	0	0	0	0	0	0	0	0	0	0	0	57.50
June 9	2	0	0	0	0	0	0	0	0	0	0	23	3	71.50
	4	2	0	0	0	0	0	0	0	0	0	90	2	84.00
	0	0	0	0	0	0	0	0	0	0	0	29	5	92.25
	0	0	0	0	0	0	0	0	0	0	0	34	2	76.75
	0	0	0	0	0	0	0	0	0	0	0	0	0	67.75
June 9	0	0	0	0	0	0	0	0	0	0	0	0	0	76.28
	0	0	0	0	0	0	0	0	0	0	0	0	0	68.75
	0	0	0	0	0	0	0	0	0	0	0	0	0	81.50
	0	0	0	0	0	0	0	0	0	0	0	0	0	91.75
	0	0	0	0	0	0	0	0	0	0	0	86	1	90.75

[illegible]

m.=noon: mt.=midnight.

TABLE LXXI.—*Time of oviposition by moths of the spring brood; observations taken daily every three hours, except at 3 a. m.; Grand Junction, Colo., 1916; summary of Table LXX.*

Number of observation periods.	Period of observation.	Total number of eggs deposited.	Average number of eggs per oviposition period.	Per cent of eggs deposited per oviposition period.	Mean temperature during oviposition periods.
					° F.
7	12 mt. to 6 a. m. . .	0	0.00	0.00	57.07
7	6 a. m. to 9 a. m. . .	0	0.00	0.00	62.64
7	9 a. m. to 12 m. . . .	10	1.42	1.54	76.39
7	12 m. to 3 p. m. . . .	92	13.14	14.20	83.75
7	3 p. m. to 6 p. m. . .	381	54.42	58.80	82.92
7	6 p. m. to 9 p. m. . .	133	19.00	20.52	73.14
7	9 p. m. to 12 mt. . .	32	4.57	4.94	64.96

m=noon; mt=midnight.

Moths of the first brood, 1916.—Oviposition studies, similar to those just described, were made with moths of the first brood during a period of one week from July 24 to 31, inclusive. The results are given in Table LXXII and presented in a summarized form in Table LXXIII.

The eggs were deposited in largest numbers from 3 p. m. to 6 p. m., with the greatest activity about dusk. With a mean temperature of 79.28° F., from 3 p. m. to 6 p. m., over 35 per cent of the eggs were laid, whereas with a lower mean temperature, 72.96° F., from 6 p. m. to 9 p. m., over 46 per cent of the eggs were deposited.

It would appear from the foregoing studies that the time of day is the most influential factor relating to the time of oviposition by moths of the spring and first broods. The moths, as a rule, are most active in depositing their eggs late in the afternoon to early in the evening, their activity being greatest just about dusk.

TABLE LXXII.—Time of oviposition by moths of the first brood; observations taken daily every three hours except at 3 a. m.; Grand Junction, Colo., 1916.

Cage No.....	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Number of eggs deposited on—		Total number of eggs deposited.	Mean temperature between observations.
Date of observation.	18	18	19	19	20	20	21	21	21	21	22	22	22	22	Number of eggs deposited on—		Total number of eggs deposited.	Mean temperature between observations.
															Folage.	Cage.		
July 24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	69	70	94.00
	1	0	0	0	0	0	0	0	0	0	0	0	0	0	347	293	640	87.50
	1	0	0	0	0	0	0	0	0	0	0	0	0	0	304	524	828	79.00
	12 mt.	47	31	0	0	0	0	0	0	0	0	0	0	0	127	126	253	74.75
	9 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	8	68.57
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72.75
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72.75
	3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	75.25
	6 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	124	87	211	72.75
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	213	212	425	73.75
	12 mt.	38	10	21	3	29	12	0	1	0	0	0	0	0	6	10	16	71.50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	10	66.85
	9 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68.50
	12 mt.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78.50
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	18	41	76.25
	3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	170	181	331	81.25
	6 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	325	90	413	75.75
	12 mt.	2	0	0	0	0	0	0	0	0	0	0	0	0	5	8	13	70.00
	9 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	66.42
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69.25
	3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	76.00
	6 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	62	14	76	80.75
	12 mt.	20	7	0	0	0	0	0	0	0	0	0	0	0	18	5	23	71.50
	9 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	87	34	121	67.50
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	7	66.00
	3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64.71
	6 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	67.50
3 p. m.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	3	23	78.25
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	24	48	84.75

m.=noon; mt.=midnight.

TABLE LXXII.—Time of oviposition by moths of the first brood; observations taken daily every three hours except at 3 a. m.; Grand Junction, Colo., 1916—Continued.

Cage No.....	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Number of eggs deposited on—		Total number of eggs deposited.	Mean temperature between observations.
	18	18	19	19	20	20	21	21	21	21	22	22	22	22				
Moths emerged July.....	18	18	19	19	20	20	21	21	21	21	22	22	22	22				
Date of observation.	Number of eggs deposited on—														Number of eggs deposited on—		Total number of eggs deposited.	Mean temperature between observations.
	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Foliage.	Cage.		
July 28	1	0	0	0	1	8	0	0	0	0	0	4	13	7	58	106	164	76.50
	0	0	0	0	2	0	0	0	0	0	0	2	12	0	44	38	69.50	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	66.25	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	63.85	
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67.50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75.75
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79.50
30	1	0	0	0	0	0	0	0	0	0	0	13	2	7	37	37	61	73.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66.25
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60.71
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66.50
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	12	87.25
	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	2	58	83.50
	0	0	0	0	0	0	0	0	0	0	0	13	7	1	28	38	72.25	
	0	0	0	0	0	0	0	0	0	0	0	6	5	3	27	11	89	72.50
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67.14
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70.50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79.50
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	.....

m. = noon; mt. = midnight.

TABLE LXXIII.—*Time of oviposition by moths of the first brood, observations taken daily every three hours, except at 3 a. m., Grand Junction, Colo., 1916; summary of Table LXXII.*

Number of observation periods.	Period of observation.	Total number of eggs deposited.	Average number of eggs per oviposition period.	Per cent of eggs deposited per oviposition period.	Mean temperature during oviposition periods.
					° F.
7	12 mt. to 6 a. m....	24	3.42	0.56	65.46
7	6 a. m. to 9 a. m....	13	1.85	0.30	68.57
7	9 a. m. to 12 m....	58	8.28	1.36	76.60
7	12 m. to 3 p. m....	268	38.28	6.27	81.64
7	3 p. m. to 6 p. m..	1,535	219.28	35.92	79.28
7	6 p. m. to 9 p. m..	1,998	285.00	46.68	72.96
7	9 p. m. to 12 mt....	381	54.42	8.91	69.60

m=noon; mt=midnight.

OVIPOSITION BY INDIVIDUAL MOTHS.

Studies of the fecundity of individual moths were made in 1915 and 1916 by isolating pairs of male and female moths in separate cages. These moths were segregated either one or two days after their emergence and were then confined in jelly-glass tumblers into which were placed daily fresh apple or pear foliage and a small piece of sponge moistened with newly made sugar solution. Each cage was examined daily for eggs.

Moths of the first brood, 1915.—As shown in Table LXXIV, the first moths in this study emerged July 26, while the last pair, No. 83, emerged August 19. The summarized results of the observations show that the 83 moths deposited a total of 3,762 eggs, or an average of 45.33 eggs per female. The maximum number of eggs laid by a single individual was 185; the average number of eggs laid by a single female in one day was 10.84 and the maximum 80.

Attention is here drawn to certain facts as revealed by a comparison of Tables XVI and LXXIV. It will be noted in the former table, which gives in detail the oviposition data of moths of the first brood confined, in 1915, in the usual large battery-jar cages, that 46.73 was the average number of eggs deposited per female moth, while 45.33 was the average number deposited per female by the individual caging method, as shown in the latter table. This latter method seems to have reduced the length of the period of oviposition as well as delayed it somewhat. However, as will be seen by a comparison of Tables XVII and LXXIV, the average length of life of the female moth was about the same by either method, it being 12.68 days when the moths were confined in the large battery-jar cages and 12.80 days when caged individually. A detailed record of this and other important oviposition data obtained by the individual caging method in 1915 is given completely in Table LXXIV.

TABLE LXXIV.—*Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1915.*

Pair No.	Date of—				Period (in days).				Total length of life of female moth	Number of days on which oviposition occurred.	Total number of eggs deposited.	Average number of eggs per oviposition.	Maximum number of eggs deposited in one day.
	Emergence of moths.	First oviposition.	Last oviposition.	Death of female moth.	Before oviposition.	Of oviposition.	From date of emergence to last oviposition.	Of life of female after oviposition.					
1	July 26	July 28	Aug. 3	Aug. 4	2	7	8	1	Days.	5	29	5.8	12
2	July 27	July 29	do.	Aug. 5	2	6	7	2	9	2	2	1.0	1
3	Aug. 2	Aug. 4	Aug. 10	Aug. 15	2	7	8	5	13	4	31	3.8	24
4	Aug. 4	Aug. 5	Aug. 5	Aug. 8	1	1	1	3	4	1	16	16.0	16
5	do.	Aug. 6	Aug. 6	Aug. 16	2	1	2	10	12	1	2	2.0	2
6	do.	do.	Aug. 14	do.	2	9	10	2	12	8	115	14.4	47
7	do.	do.	Aug. 13	Aug. 17	2	8	9	4	13	4	14	3.5	8
8	do.	do.	Aug. 11	Aug. 15	2	6	7	4	11	5	121	24.2	38
9	do.	do.	Aug. 12	do.	2	7	8	3	11	6	136	22.7	51
10	do.	do.	Aug. 9	Aug. 12	2	4	5	3	8	3	19	6.3	10
11	do.	do.	Aug. 15	Aug. 16	2	10	11	1	12	8	88	11.0	36
12	do.	do.	Aug. 13	Aug. 17	2	8	9	4	13	8	185	23.1	38
13	do.	do.	Aug. 16	do.	2	11	12	1	13	9	118	13.1	36
14	do.	Aug. 7	do.	Aug. 19	3	10	12	3	15	2	2	1.0	1
15	do.	do.	do.	do.	3	10	12	3	15	7	39	5.6	15
16	do.	do.	Aug. 11	Aug. 11	3	5	7	0	7	5	95	19.0	26
17	do.	Aug. 8	Aug. 13	Aug. 19	4	6	9	6	15	5	77	15.4	44
18	do.	do.	Aug. 9	Aug. 16	4	2	5	7	12	2	2	1.0	1
19	do.	Aug. 10	Aug. 13	do.	6	4	9	3	12	4	46	11.5	28
20	Aug. 6	Aug. 8	do.	Aug. 14	2	6	7	1	8	6	103	17.2	58
21	do.	do.	Aug. 9	Aug. 12	2	2	3	3	6	2	30	15.0	27
22	do.	do.	Aug. 10	Aug. 13	2	3	4	3	7	2	30	15.0	27
23	do.	do.	do.	do.	2	3	4	3	7	3	103	34.3	73
24	do.	Aug. 9	do.	do.	3	2	4	3	7	2	5	2.5	3
25	do.	Aug. 10	Aug. 18	Aug. 19	4	9	12	1	13	7	22	3.1	6
26	Aug. 7	Aug. 16	Aug. 20	Aug. 21	9	5	13	1	14	4	16	4.0	7
27	do.	Aug. 9	Aug. 14	Aug. 17	2	6	7	3	10	1	71	17.8	24
28	do.	Aug. 15	Aug. 15	do.	8	1	8	2	10	1	3	3.0	3
29	do.	Aug. 16	Aug. 16	do.	9	1	9	1	10	1	3	3.0	3
30	Aug. 8	Aug. 10	Aug. 17	Aug. 20	2	8	9	3	12	5	25	5.0	9
31	do.	do.	Aug. 11	Aug. 12	2	2	3	1	4	2	6	3.0	3
32	do.	Aug. 11	do.	Aug. 19	3	1	3	8	11	1	1	1.0	1
33	do.	Aug. 12	Aug. 12	Aug. 16	4	1	4	4	8	1	32	32.0	32
34	Aug. 9	Aug. 11	do.	Aug. 19	2	2	3	7	10	2	85	42.5	68
35	do.	Aug. 12	Aug. 16	Aug. 20	3	5	7	4	11	3	22	7.3	13
36	do.	do.	Aug. 22	Aug. 24	3	11	13	2	15	8	121	15.1	30
37	do.	do.	Aug. 16	Aug. 20	3	5	7	4	11	3	22	7.3	13
38	do.	Aug. 13	Aug. 15	Aug. 19	4	3	6	4	10	3	26	8.7	13
39	do.	Aug. 14	Aug. 14	Aug. 15	5	1	5	1	6	1	25	25.0	25
40	Aug. 11	do.	Aug. 21	Aug. 22	3	8	10	1	11	6	76	12.7	21
41	do.	Aug. 15	Aug. 20	do.	4	6	9	2	11	6	28	4.7	11
42	do.	do.	Aug. 15	Aug. 18	4	1	4	3	7	1	15	15.0	15
43	do.	do.	Aug. 27	Aug. 31	4	13	16	4	20	7	34	4.9	12
44	do.	Aug. 16	Aug. 16	Aug. 23	5	1	5	7	12	1	3	3.0	3
45	Aug. 13	Aug. 17	Aug. 23	Aug. 26	4	7	10	3	13	4	7	1.8	3
46	do.	do.	Sept. 1	Sept. 2	4	16	19	1	20	10	63	6.3	15
47	do.	Aug. 18	Aug. 31	Sept. 3	5	14	18	3	21	13	170	13.1	56
48	do.	do.	Aug. 18	Aug. 22	5	1	5	4	9	1	3	3.0	3
49	do.	Aug. 19	Aug. 21	Aug. 26	6	6	11	2	13	4	69	17.3	62
50	do.	do.	Aug. 29	Aug. 29	6	11	16	0	16	9	158	17.6	63
51	do.	Aug. 22	Aug. 27	do.	9	6	14	2	16	3	21	8.0	11
52	do.	do.	Aug. 29	Sept. 1	9	8	16	3	19	3	20	6.7	10
53	do.	Aug. 23	Sept. 2	Sept. 8	10	11	20	6	26	8	45	5.6	19
54	do.	Aug. 24	Sept. 1	Sept. 2	11	9	19	1	20	4	7	1.8	2
55	do.	Aug. 29	Sept. 2	Sept. 3	16	5	20	1	21	4	16	4.0	6
56	do.	Aug. 30	Aug. 30	Aug. 31	17	1	17	1	18	1	4	4.0	4
57	do.	Aug. 19	Aug. 30	Aug. 27	6	5	10	4	14	4	63	15.8	50
58	do.	Aug. 20	Aug. 20	do.	7	1	7	7	14	1	5	5.0	5
59	Aug. 15	Aug. 18	Aug. 22	Aug. 26	3	5	7	4	11	5	120	24.0	37
60	do.	do.	do.	do.	3	5	7	4	11	5	90	18.0	28
61	do.	do.	Aug. 21	Aug. 31	3	7	9	7	16	3	9	3.0	7
62	do.	Aug. 19	Aug. 28	Aug. 29	4	10	13	1	14	9	101	11.2	39
63	do.	Aug. 20	Aug. 20	Aug. 22	5	1	5	2	7	1	13	13.0	13
64	do.	do.	Aug. 27	Sept. 1	5	8	12	5	17	6	30	5.0	9
65	do.	Aug. 23	Aug. 24	do.	8	2	9	8	17	2	6	3.0	5
66	Aug. 19	Aug. 22	Aug. 25	Aug. 27	3	4	6	2	8	3	29	9.7	24
67	do.	do.	Aug. 26	do.	3	5	7	1	8	4	123	30.8	80
68	do.	do.	Aug. 23	Aug. 29	3	2	4	6	10	2	17	8.5	16
69	do.	do.	Sept. 4	Sept. 5	3	13	16	1	17	10	110	11.0	41

TABLE LXXIV.—*Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1915—Continued.*

Pair No.	Date of—				Period (in days).				Total length of life of female moth.	Number of days on which oviposition occurred.	Total number of eggs deposited.	Average number of eggs per oviposition.	Maximum number of eggs deposited in one day.
	Emergence of moths.	First oviposition.	Last oviposition.	Death of female moth.	Before oviposition.	Of oviposition.	From date of emergence to last oviposition.	Of life of female after oviposition.					
70	Aug. 19	Aug. 22	Aug. 30	Aug. 31	3	9	11	1	Days. 12	8	82	10.3	50
71	..do.	..do.	Aug. 25	..do.	3	4	6	6	12	4	83	20.8	46
72	..do.	Aug. 23	Aug. 29	Sept. 1	4	7	10	3	13	4	27	6.8	12
73	..do.	..do.	Aug. 30	Aug. 31	4	8	11	1	12	6	55	9.2	19
74	..do.	Aug. 25	Sept. 1	Sept. 2	6	8	13	1	14	3	19	6.3	9
75	..do.	..do.	Aug. 29	Sept. 1	6	5	10	3	13	5	32	6.4	9
76	..do.	Aug. 26	..do.	Aug. 31	7	4	10	2	12	3	18	6.0	11
77	..do.	..do.	..do.	Sept. 1	7	4	10	3	13	2	12	6.0	10
78	..do.	Aug. 27	Sept. 7	Sept. 10	8	12	19	3	22	8	24	3.0	5
79	..do.	Aug. 28	..do.	Sept. 8	9	11	19	1	20	6	30	5.0	10
80	..do.	Aug. 29	Aug. 31	Sept. 2	10	3	12	2	14	2	8	4.0	5
81	..do.	Sept. 1	Sept. 1	Sept. 8	13	1	13	7	20	1	9	9.0	9
82	..do.	..do.	Sept. 9	Sept. 12	13	9	21	3	24	4	13	3.3	7
83	..do.	Sept. 2	Sept. 2	Sept. 5	14	1	14	3	17	1	4	4.0	4
Total.										347	3,762	.....	.....

SUMMARY.

	Average.	Maximum.	Minimum.
Number of days from emergence to first oviposition.....	4.90	17	1
Number of days from emergence to last oviposition.....	9.66	21	1
Number of days in period during which female was depositing eggs.....	5.75	16	1
Number of days on which oviposition occurred.....	4.18	13	1
Number of days female moth lived after last oviposition..	3.12	10	0
Total length of life of female moth in days.....	12.86	26	4
Number of eggs deposited by one female moth.....	45.33	185	1
Number of eggs deposited by one female moth in one day.	10.84	80	0

In Table LXXV it will be noted that 14 moths have an oviposition record of 100 or more eggs, one having laid 185 eggs, two over 150 eggs, one over 125, and ten between 100 and 125 eggs.

TABLE LXXV.—*Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1915; data taken from Table LXXIV.*

Number of eggs deposited by individual moths.			
100 to 125	125 to 150	150 to 175	175 to 200
101	136	158	185
103			
103		170	
110			
115			
118			
120			
121			
121			
123			

Moths of the first brood, 1916.—The study of the number of eggs deposited by moths of the first brood was continued in 1916 on a more extensive scale than during the preceding year. The methods employed, however, were identical in all respects. The data herewith given were obtained by recording daily the number of eggs laid by 201 female moths, beginning with moths that emerged July 11 and ending with moths that issued August 22. As will be seen in Table LXXVI, these 201 individuals deposited a total of 17,225 eggs, or an average of 85.70 eggs per female.

TABLE LXXVI.—*Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1916.*

Pair No.	Date of—				Period (in days).				Total length of life of female moth.	Number of days on which oviposition occurred.	Total number of eggs deposited.	Average number of eggs per oviposition.	Maximum number of eggs deposited in one day.
	Emergence of moths.	First oviposition.	Last oviposition.	Death of female moth.	Before oviposition.	Of oviposition.	From date of emergence to last oviposition.	Of life of female after oviposition.					
1	July 11	July 13	July 22	July 23	2	10	11	1	Days. 12	9	229	25.4	57
2	do	July 14	July 21	July 22	3	8	10	1	11	109	21.8	38	
3	do	July 19	July 25	July 27	8	7	14	2	16	15	3.0	6	
4	do	do	July 23	July 28	8	5	12	5	17	48	9.6	29	
5	do	do	do	July 16	5				5	0			
6	do	July 20	July 20	July 23	9	1	9	3	12	1	3	3.0	3
7	July 12	July 17	July 23	July 26	5	7	11	3	14	7	185	26.4	67
8	do	July 15	do	July 30	3	9	11	7	18	8	192	24.0	45
9	do	July 14	July 14	July 24	2	1	2	10	12	1	39	39.0	39
10	do	July 21	July 21	July 26	9	1	9	5	14	1	6	6.0	6
11	do	July 19	July 23	do	7	5	11	3	14	3	5	1.7	3
12	do	do	(¹)								0		
13	July 13	July 23	July 29	July 30	10	7	16	1	17	5	12	2.4	6
14	do	July 18	July 26	July 28	5	9	13	2	15	9	186	20.7	66
15	do	do	July 25	do	5	8	12	3	15	8	55	6.9	27
16	do	July 15	July 27	July 27	2	13	14	0	14	13	199	15.3	64
17	do	do	July 20	July 21	2	6	7	1	8	6	107	17.8	36
18	do	do	July 21	(¹)	2	7	8			7	185	26.4	54
19	do	July 16	do	July 25	3	6	8	4	12	5	127	25.4	54
20	do	do	July 18	do	3	3	5	7	12	3	146	48.7	77
21	do	do	do	Aug. 5					23		0		
22	do	July 29	July 29	July 29	16	1	16	0	16	1	1	1.0	1
23	July 14	July 16	July 21	July 22	2	6	7	1	8	6	159	26.5	48
24	do	July 22	July 29	July 30	8	8	15	1	6	4	9	2.3	4
25	do	July 23	do	do	9	7	15	1	6	5	46	9.2	21
26	do	July 16	July 31	Aug. 1	2	16	17	1	18	8	89	11.1	45
27	do	do	July 29	July 29	2	14	15	0	15	11	69	6.3	10
28	do	July 18	do	do	4	12	15	0	15	10	245	24.5	74
29	do	July 16	Aug. 1	Aug. 2	2	17	18	1	19	10	58	5.8	22
30	do	do	do	July 17					3		0		
31	do	do	do	July 25					11		0		
32	July 15	July 17	July 22	July 30	2	6	7	8	15	5	99	19.8	40
33	do	July 20	July 20	July 20	5	1	5	0	5	1	8	8.0	8
34	do	July 17	July 27	July 28	2	11	12	1	13	11	266	24.2	78
35	do	July 18	July 30	July 30	3	13	15	0	15	13	168	12.9	48
36	do	July 19	Aug. 3	Aug. 4	4	16	19	1	20	7	21	3.0	8
37	do	July 31	Aug. 5	Aug. 7	16	6	21	2	23	6	20	3.3	8
38	do	July 18	July 30	July 31	3	13	15	1	16	11	207	18.8	51
39	do	July 22	Aug. 5	Aug. 6	7	15	21	1	22	13	77	5.9	18
40	do	do	do	July 17					2		0		
41	do	July 24	Aug. 7	Aug. 9	9	15	23	2	25	3	3	1.0	1
42	July 16	July 18	July 29	Aug. 1	2	12	13	3	16	5	120	24.0	76
43	do	do	July 24	July 30	2	7	8	6	14	4	7	1.8	3
44	do	do	do	Aug. 3	6	13	18	0	18	13	271	20.8	54
45	do	July 22	Aug. 3	Aug. 3	2	6	7	2	9	6	151	25.2	87
46	do	July 18	July 23	July 25	2	6	8	14	2	16	7	11.3	45
47	do	July 23	July 30	Aug. 1	6	11	16	0	16	5	8	1.6	3
48	do	July 22	Aug. 1	do	4	27	30	1	31	14	35	2.5	6

¹ Date of death unknown.

TABLE LXXVI.—Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1916—Continued.

Pair No.	Date of—				Period (in days).				Total length of life of female moth.	Number of days on which oviposition occurred.	Total number of eggs deposited.	Average number of eggs per oviposition.	Maximum number of eggs deposited in one day.	
	Emergence of moths.	First oviposition.	Last oviposition.	Death of female moth.	Before oviposition.	Of oviposition.	From date of emergence to last oviposition.	Of life of female after oviposition.						
49	July 16	July 19	July 31	Aug. 1	3	13	15	1	Days. 16	11	119	10.8	31	
50	..do.	..do.	..do.	July 29	7	8	14	1	13	8	0			
51	July 17	July 24	July 31	July 1	6	11	16	0	15	8	67	8.4	20	
52	..do.	July 23	Aug. 2	July 2	3	10	13	2	16	10	128	12.8	71	
53	..do.	July 20	July 30	July 1	3	10	13	2	15	8	95	11.9	31	
54	..do.	July 19	July 28	July 29	2	10	11	1	12	10	213	21.3	47	
55	..do.	July 22	Aug. 2	Aug. 2	5	12	16	0	16	10	175	17.5	81	
56	..do.	July 19	July 27	July 30	2	9	10	3	13	9	258	28.7	81	
57	..do.	July 22	Aug. 4	Aug. 4	5	14	18	0	18	12	90	7.5	16	
58	..do.	July 21	July 31	July 31	4	11	14	0	14	11	195	17.7	51	
59	..do.	July 19	July 28	July 30	2	10	11	2	13	8	121	15.1	61	
60	..do.	July 23	July 27	Aug. 1	6	5	10	5	15	2	2	1.0	1	
61	July 18	July 20	July 30	Aug. 2	2	11	12	3	15	11	215	19.5	62	
62	..do.	..do.	..do.	July 31	2	11	12	1	13	10	126	12.6	28	
63	..do.	July 22	Aug. 6	Aug. 7	4	16	19	1	20	9	101	1.1	56	
64	..do.	..do.	July 31	Aug. 2	4	10	13	2	15	9	139	15.4	58	
65	..do.	July 20	July 29	July 29	2	10	11	0	11	10	236	23.6	69	
66	..do.	July 22	July 31	Aug. 2	4	10	13	2	15	9	183	20.3	69	
67	..do.	..do.	Aug. 1	Aug. 4	4	11	14	3	17	4	5	1.3	2	
68	..do.	..do.	July 22	July 26	4	1	4	4	8	1	2	2.0	2	
69	..do.	July 26	July 26	Aug. 2	8	1	8	7	15	1	1	1.0	1	
70	July 19	July 21	July 31	..do.	2	11	12	2	14	5	22	4.4	8	
71	..do.	July 28	Aug. 6	Aug. 7	9	10	18	1	19	8	56	7.0	20	
72	..do.	July 22	July 31	Aug. 1	3	10	12	1	13	10	165	16.5	37	
73	..do.	July 28	Aug. 2	Aug. 5	9	6	14	3	17	4	20	5.0	7	
74	..do.	July 24	July 30	July 30	5	7	11	0	11	7	126	18.0	27	
75	..do.	July 28	Aug. 3	Aug. 4	9	7	15	1	16	6	98	16.3	38	
76	..do.	..do.	..do.	July 29	Aug. 3	14	1	14	7	21	2	2.0	2	
77	..do.	Aug. 2	Aug. 2	Aug. 9	Aug. 3	4	13	16	1	17	9	223	24.8	111
78	..do.	..do.	..do.	Aug. 3	5	16	20	5	25	9	20	2.2	5	
79	July 20	July 24	Aug. 5	Aug. 6	4	13	16	1	17	9	223	24.8	111	
80	..do.	July 25	Aug. 9	Aug. 14	5	16	20	5	25	9	20	2.2	5	
81	..do.	July 24	Aug. 4	Aug. 4	4	12	15	0	15	10	55	5.5	15	
82	..do.	July 22	Aug. 5	Aug. 7	2	15	16	2	18	10	200	20.0	109	
83	..do.	July 25	July 30	July 30	5	6	10	0	10	6	165	27.5	44	
84	..do.	July 23	..do.	Aug. 1	3	8	10	2	12	8	252	31.5	89	
85	..do.	July 22	Aug. 6	Aug. 9	2	16	17	3	20	9	29	3.2	9	
86	July 21	..do.	July 29	July 30	1	8	8	1	9	6	102	17.0	47	
87	..do.	July 23	July 30	Aug. 5	2	8	9	6	15	6	91	15.2	40	
88	..do.	July 31	Aug. 8	Aug. 9	10	9	18	1	19	9	181	20.1	50	
89	..do.	July 25	Aug. 17	Aug. 18	4	24	27	1	28	20	136	6.8	22	
90	..do.	..do.	..do.	July 28	Aug. 13	13	1	13	7	21	2	2.0	2	
91	Aug. 5	Aug. 7	Aug. 24	Aug. 25	2	18	19	1	20	17	316	18.6	112	
92	Aug. 6	..do.	Aug. 17	Aug. 18	1	11	11	1	12	11	240	21.8	52	
93	..do.	Aug. 14	Aug. 28	Aug. 29	8	15	22	1	23	12	249	20.8	106	
94	..do.	Aug. 11	..do.	Sept. 1	5	18	22	4	26	7	13	1.9	3	
95	..do.	Aug. 14	Aug. 21	Aug. 23	8	8	15	2	17	8	175	21.9	69	
96	..do.	..do.	Aug. 17	..do.	8	4	11	6	17	3	21	7.0	19	
97	..do.	Aug. 8	Aug. 14	Aug. 20	2	7	8	6	14	6	88	14.7	47	
98	..do.	..do.	..do.	Aug. 23	Aug. 13	13	1	13	7	21	2	2.0	2	
99	..do.	Aug. 8	Aug. 19	Aug. 19	2	12	13	0	13	2	2	1.0	1	
100	..do.	..do.	..do.	Aug. 13	Aug. 13	13	1	13	7	21	2	0	0	
101	..do.	Aug. 19	Aug. 19	Sept. 4	13	1	13	16	29	1	2	2.0	2	
102	Aug. 8	Aug. 10	Aug. 27	(1)	2	18	19	1	16	8	56	7.0	18	
103	..do.	Aug. 12	Aug. 23	Aug. 24	4	12	15	1	16	11	39	3.5	12	
104	..do.	Aug. 11	Aug. 17	Aug. 20	3	7	9	3	12	7	158	22.6	49	
105	..do.	Aug. 15	Aug. 22	Aug. 24	7	8	14	2	16	5	8	1.6	2	
106	..do.	Aug. 14	Aug. 16	Aug. 18	6	3	8	2	10	3	133	44.3	115	
107	..do.	Aug. 25	Sept. 4	Sept. 5	17	11	27	1	28	2	3	1.5	2	
108	..do.	Aug. 12	Aug. 18	Aug. 21	4	7	10	3	13	2	4	2.0	3	
109	Aug. 9	Aug. 17	Aug. 19	Aug. 22	8	3	10	3	13	3	7	2.3	4	
110	..do.	..do.	..do.	Aug. 19	8	3	10	0	10	3	20	6.7	10	
111	..do.	Aug. 18	Aug. 31	(1)	9	14	22	6	33	10	29	2.9	6	
112	..do.	Aug. 11	Sept. 5	Sept. 11	2	26	27	6	33	16	74	4.6	17	
113	..do.	..do.	Aug. 29	Aug. 30	2	19	20	1	21	18	227	12.6	25	
114	..do.	..do.	Aug. 23	Aug. 24	2	13	14	1	15	6	22	3.7	13	

(1) Date of death unknown.

TABLE LXXVI.—Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1916—Continued.

Pair No.	Date of—				Period (in days).				Total length of life of female moth.	Number of days on which oviposition occurred.	Total number of eggs deposited.	Average number of eggs per oviposition.	Maximum number of eggs deposited in one day.
	Emergence of moths.	First oviposition.	Last oviposition.	Death of female moth.	Before oviposition.	Of oviposition.	From date of emergence to last oviposition.	Of life of female after oviposition.					
115	Aug. 9	Aug. 14	Aug. 28	Sept. 2	5	15	19	5	24	14	116	8.3	22
116	Aug. 11	Aug. 30	Aug. 30	Aug. 31	2	20	21	1	22	19	88	4.6	9
117	Aug. 16	Aug. 16	Aug. 16	Aug. 22	7	1	7	8	13	1	1	1.0	1
118	Aug. 10	Aug. 16	Aug. 28	Aug. 24	6	13	18	1	19	11	188	17.1	54
119	Aug. 12	Aug. 25	Aug. 25	Aug. 29	2	14	15	0	15	10	112	11.2	44
121	Aug. 15	Aug. 23	Aug. 23	Aug. 29	5	9	13	6	19	8	142	17.8	43
122	Aug. 23	Aug. 31	Sept. 2	Sept. 2	13	9	21	2	23	6	50	8.3	31
123	Aug. 18	Aug. 19	Sept. 3	Sept. 3	8	2	9	15	24	2	3	2.5	2
124	Aug. 26	Aug. 26	Aug. 26	Aug. 26	16				16		0		
125	Aug. 25	Aug. 25	Aug. 25	Aug. 25	15				15		0		
126	Aug. 17	Aug. 24	Aug. 24	Aug. 30	7	8	14	6	20	3	4	1.3	2
127	Aug. 25	Aug. 31	(1)	Aug. 31	15	7	21			4	7	1.8	3
128	Aug. 18	Aug. 19	Aug. 30	Aug. 30	8	2	9	11	20	2	6	3.0	4
129	Aug. 11	Aug. 12	Aug. 27	Aug. 27	1	16	16	0	16	13	133	10.2	51
130	Aug. 15	Sept. 8	Sept. 11	Sept. 11	4	25	28	3	31	24	210	8.8	37
131	Aug. 19	Aug. 29	Aug. 31	Aug. 31	8	11	18	2	20	8	27	3.4	10
132	Aug. 17	Aug. 25	Aug. 26	Aug. 26	6	9	14	1	15	6	65	10.8	22
133	Sept. 13	Sept. 13	Sept. 13	Sept. 13	6	28	33	0	33	24	139	5.8	15
134	Sept. 2	Sept. 11	Sept. 11	Sept. 11	22	10	31	2	33	5	6	1.2	2
135	Aug. 14	Sept. 3	Sept. 3	Sept. 6	3	21	23	3	26	18	251	13.9	39
136	Aug. 15	Sept. 9	Sept. 9	Sept. 13	4	26	29	4	33	22	116	5.3	13
137	Aug. 14	Aug. 14	Aug. 14	Aug. 22	3	1	3	8	11	1	2	2.0	2
138	Aug. 23	Aug. 23	Aug. 23	Aug. 23	12				12		0		
139	Aug. 13	Aug. 16	Aug. 21	Aug. 21	3	6	8	2	10	3	82	27.3	49
140	Aug. 15	Aug. 28	(1)	Aug. 28	2	14	15			12	213	17.8	34
141	Aug. 16	Aug. 24	Aug. 26	Aug. 26	2	10	11	2	13	9	144	16.0	34
142	Aug. 16	Aug. 29	Aug. 30	Aug. 30	3	14	16	1	17	10	120	12.0	33
143	Aug. 18	Aug. 26	Aug. 31	Aug. 31	5	9	13	5	18	7	103	14.7	72
144	Aug. 15	Aug. 18	Aug. 19	Aug. 19	2	4	5	1	6	4	61	15.3	33
145	Aug. 18	Aug. 25	Aug. 25	Aug. 25	5	8	12	0	12	7	163	23.3	41
146	Aug. 23	Aug. 23	Aug. 24	Aug. 24	10	1	10	1	11	1	2	2.0	2
147	Aug. 28	Aug. 28	Sept. 8	Sept. 8	15	1	15	11	26	1	2	2.0	2
148	Aug. 17	Aug. 19	Aug. 24	Aug. 24	4	3	16	5	11	2	2	1.0	1
149	Aug. 15	Sept. 3	Sept. 4	Sept. 4	1	20	20	1	21	9	28	3.1	8
150	Aug. 18	Aug. 25	Aug. 26	Aug. 26	4	8	11	1	12	3	10	3.3	5
151	Aug. 22	Aug. 27	Aug. 28	Aug. 28	8	6	13	1	14	5	43	8.6	18
152	Aug. 17	Aug. 17	Aug. 17	Aug. 17	3	11	13	1	14	11	227	20.6	71
153	Aug. 16	Sept. 6	Sept. 11	Sept. 11	2	22	23	5	28	21	308	14.7	52
154	Aug. 17	Aug. 27	Sept. 3	Sept. 3	3	11	13	7	20	7	80	11.4	41
155	Aug. 18	Aug. 31	(1)	Aug. 31	4	14	17			13	223	17.2	45
156	Aug. 21	Sept. 1	Sept. 2	Sept. 2	7	12	18	1	19	10	99	9.9	20
157	Aug. 19	Aug. 19	Aug. 20	Aug. 20	5	1	5	1	6	1	3	3.0	3
158	Aug. 30	Aug. 30	Aug. 30	Aug. 30	16				16		0		
159	Aug. 15	Aug. 17	Aug. 31	Sept. 2	2	15	16	2	18	15	252	1.7	41
160	Aug. 18	Aug. 21	Aug. 25	Aug. 25	3	4	6	4	10	4	33	8.3	19
161	Aug. 29	Aug. 29	(1)	Aug. 29	3	12	14			10	186	18.6	59
162	Aug. 23	Sept. 3	Sept. 5	Sept. 5	8	12	19	2	21	7	17	2.4	8
163	Aug. 18	Aug. 18	Aug. 21	Aug. 21	3	1	3	3	6	1	8	8.0	8
164	Aug. 20	Aug. 26	Aug. 26	Aug. 26	3	3	5	6	11	3	21	7.0	10
165	Aug. 17	Aug. 28	Aug. 29	Aug. 29	2	12	13	1	14	11	221	2.0	60
166	Aug. 19	Aug. 31	Sept. 1	Sept. 1	4	13	16	1	17	4	6	1.5	3
167	Aug. 24	Aug. 29	Sept. 2	Sept. 2	9	6	14	4	18	3	6	2.0	3
168	Aug. 21	Aug. 21	Sept. 1	Sept. 1	6	1	6	11	17	1	1	1.0	1
169	Aug. 16	Aug. 27	Sept. 1	Sept. 6	11	6	16	5	21	5	10	2.0	4
170	Aug. 26	Sept. 3	Sept. 4	Sept. 4	10	9	18	1	19	5	16	3.2	7
171	Aug. 18	Aug. 24	Aug. 28	Aug. 28	2	7	8	4	12	4	134	33.5	89
172	Aug. 27	Aug. 28	Sept. 2	Sept. 2	11	2	12	5	17	2	2	1.0	1
173	Aug. 30	Aug. 30	Sept. 1	Sept. 1	14	1	14	2	16	1	1	1.0	1
174	Aug. 26	Aug. 28	Aug. 28	Aug. 28	10	3	12	4	16	2	4	2.0	3
175	Aug. 24	Aug. 24	Aug. 24	Aug. 24	18				18		0		
176	Aug. 18	Aug. 21	Aug. 31	(1)	3	11	13			11	277	25.2	59
177	Aug. 20	Aug. 28	Aug. 29	Aug. 29	2	9	10	1	11	9	168	18.7	68
178	Aug. 25	Aug. 29	Sept. 10	Sept. 10	7	5	11	12	23	2	2	1.0	1
179	Aug. 20	Aug. 20	Sept. 1	Sept. 1	2	10	11	3	14	9	71	7.9	18
180	Aug. 24	Aug. 31	Sept. 4	Sept. 4	17				17		0		
181	Aug. 24	Aug. 31	Sept. 1	Sept. 1	6	8	13	1	14	3	3	1.0	1
182	Aug. 25	Aug. 27	Sept. 2	Sept. 2	7	3	9	6	15	2	3	1.5	2

¹ Date of death unknown.

TABLE LXXVI.—*Oviposition by individual codling moths of the first brood, Grand Junction, Colo., 1916—Continued.*

Pair No.	Date of—				Period (in days).				Total length of life of female moth.	Number of days on which oviposition occurred.	Total number of eggs deposited.	Average number of eggs per oviposition.	Maximum number of eggs deposited in one day.
	Emergence of moths.	First oviposition.	Last oviposition.	Death of female moth.	Before oviposition.	Of oviposition.	From date of emergence to last oviposition.	Of life of female after oviposition.					
183	Aug. 21	Aug. 24	Sept. 9	Sept. 9	3	17	19	0	<i>Days.</i> 19	14	247	17.6	46
184	do.	do.	Sept. 14	(1)	3	22	24		20	20	135	6.8	20
185	do.	do.	Sept. 8	Sept. 10	3	16	18	2	20	14	309	22.1	76
186	do.	Aug. 26	Sept. 3	Sept. 12	5	9	13	9	22	6	13	2.2	4
187	do.	Aug. 24	Sept. 2	Sept. 3	3	10	12	1	13	7	80	11.3	28
188	do.	do.	Sept. 4	Sept. 6	3	12	14	2	16	5	12	2.4	4
189	do.	Aug. 26	Sept. 17	Sept. 18	5	23	27	1	28	16	50	3.1	7
190	do.	Aug. 25	Sept. 8	Sept. 11	4	15	18	3	21	8	21	2.6	5
191	do.	Aug. 22	Aug. 29	Sept. 5	1	8	8	7	15	7	87	12.4	29
192	Aug. 22	Aug. 24	Sept. 24	Sept. 25	2	32	33	1	34	31	203	6.5	17
193	do.	Aug. 31	Sept. 15	Sept. 18	9	16	24	3	27	11	33	3.0	13
194	do.	Aug. 26	Sept. 25	Sept. 30	4	31	34	5	39	19	47	2.5	9
195	do.	Aug. 30	Sept. 13	Sept. 17	8	15	22	4	26	10	42	4.2	14
196	do.	Aug. 25	Aug. 30	Aug. 31	3	6	8	1	9	6	157	26.2	63
197	do.	Sept. 2	Sept. 11	Sept. 14	11	10	20	3	23	7	118	16.9	55
198	do.	Aug. 28	Sept. 22	Sept. 25	6	26	31	3	34	21	182	8.7	64
199	do.	Aug. 27	Sept. 12	Sept. 13	5	17	21	1	22	12	29	2.4	5
200	do.	Aug. 24	Sept. 1	Sept. 5	2	9	10	4	14	5	9	1.8	3
201	do.	Aug. 28	do.	do.	6	5	10	4	14	4	32	8.0	8
Total										1,467	17,225		

¹Date of death unknown.

SUMMARY.

	Average.	Maximum.	Minimum.
Number of days from emergence to first oviposition	5.19	22	1
Number of days from emergence to last oviposition.	14.47	34	2
Number of days in period during which female was depositing eggs.	10.26	32	1
Number of days on which oviposition occurred	8.06	31	1
Number of days female moth lived after last oviposition.	2.80	16	0
Total length of life of female moth in days.	16.42	39	3
Number of eggs deposited by one female moth.	85.70	316	0
Number of eggs deposited by one female moth in one day	11.74	115	0

It will be noted also in this table that the female moth of pair No. 91 deposited 316 eggs, which is, so far as the writers are aware, the highest number of eggs ever recorded from one individual codling moth. This moth was seen in copula on August 7, or two days after issuance, and two days later, August 9, deposited 112 eggs, or over one-third of her total. Another moth, of pair No. 106, emerged August 8, but did not deposit an egg until August 14, on this date laying 115 eggs. This is believed to be the highest recorded number of eggs deposited in one day by an individual codling moth. In addition to this moth several other females deposited over 100 eggs in one day, the average being 11.74.

A comparison of Tables XLII and LXXVI will show that the average number of eggs per female was greater in 1916, but that, as in 1915, the period of oviposition was shortened somewhat and that it was also delayed where the pairs were confined alone in individual cages. However, in 1916, the female lived for an average of 12.20 days when confined with other moths in a large battery-jar cage, as shown in Table XLIII, compared with 16.42 days when caged individually. Other important phases of the individual oviposition studies of 1916 are given in detail in Table LXXVI.

An abbreviated table giving the data for all of the moths that deposited 100 or more eggs is given herewith. (See Table LXXVII.) Referring to this table, it will be noted that 3 moths deposited over 300 eggs each, 1 moth deposited between 275 and 300 eggs, 6 moths between 250 and 275 eggs, 8 moths between 225 and 250 eggs, 10 moths between 200 and 225 eggs, 13 moths between 175 and 200 eggs, 9 moths between 150 and 175 eggs, 14 moths between 125 and 150 eggs, and 14 moths between 100 and 125 eggs.

TABLE LXXVII.—*Oviposition by individual coding moths of the first brood, Grand Junction, Colo., 1916. Data taken from Table LXXVI.*

Number of eggs deposited.								
100 to 125	125 to 150	150 to 175	175 to 200	200 to 225	225 to 250	250 to 275	275 to 300	300 to 325
101	126	151	175	200	227	251	277	308
102	126	157	175	203	227	252		309
103	127	158	181	207	229	252		316
107	128	159	182	210	236	258		
109	133	163	183	213	240	266		
112	133	165	185	213	245	271		
113	134	165	185	215	247			
116	135	168	186	221	249			
116	136	168	186					
118	139		188	223				
119	139		192					
120	142		195					
120	144		199					
121	146							

DEPOSITION OF INFERTILE EGGS.

On July 15, 1915, 30 female moths of the first brood which emerged on this day were confined alone in a cage to find the number of eggs deposited when male moths were not present. The results are given in Table LXXVIII, in which it will be seen that a total of 232 eggs were deposited, or an average of 7.40 eggs per moth.

TABLE LXXVIII.—*Deposition of infertile codling moth eggs, Grand Junction, Colo., 1915 (30 female moths emerged July 15).*

Number of eggs deposited.	Date of deposition.	Number of dead moths.	Date of death of moths.
2	July 18	1	July 21
3	19	3	23
30	20	5	24
16	21	1	25
8	22	3	26
42	23	1	27
31	24	2	28
4	26	1	29
40	27	3	30
6	28	2	31
12	29	2	Aug. 1
35	30	1	2
3	Aug. 1	3	3
		1	4
		1	5
232	.....	30	.....

TIME REQUIRED FOR CODLING-MOTH LARVA TO LEAVE THE EGG.

The following notes were made July 30, 1915, on the time required for a codling-moth larva to leave the egg.

Egg No. 1.—At 1.10 p. m. there was a small rent in the chorion and at 1.50 p. m. the larva had completely left the eggshell.

Egg No. 2.—At 1.15 p. m. the larva had cut a small opening in the eggshell, and had hatched by 1.23 p. m.

Egg No. 3.—At 1.20 p. m. the larva was found moving its body and mandibles intermittently until 2.03 p. m. It hatched at 2.06 p. m.

Egg No. 4.—The eggshell was found slightly opened at 2.09 p. m. The larva hatched at 2.13 p. m.

Egg No. 5.—This egg was slightly open at 2.18 p. m., and although the larva made repeated attempts to extricate itself it did not accomplish its task until 2.55 p. m.

As previously stated, the codling-moth larva normally tears a small opening in the eggshell by means of its mandibles and then passes out of the shell head foremost.

LARVÆ THAT FAIL TO EXTRICATE THEMSELVES FROM THE CHORION.

On several occasions larvæ were found dead after having partially extricated themselves from the chorion. In these instances it was noted that the anal end was protruding through the cut in the eggshell, but that the larva was held from freeing itself on account of the cervical shield and head, which were too large to pass through the opening. Normally, as previously mentioned, the larva tears a slit in the eggshell by means of its mandibles and then passes head first through the rent.

HABITS OF NEWLY HATCHED LARVÆ.

The natural instinct of newly-hatched insect larvæ is to seek suitable food on which to commence feeding. In the case of the codling moth the fruit of the apple and pear is the preferred food, but the larvæ will also attack the foliage and occasionally will burrow into the tips of tender twigs. The injury to the foliage is of little consequence, consisting of small holes through the lower epidermis, usually where the leaf is fleshy, as at the junction of the veins with the midrib.

The frequency and amount of foliage feeding depend mainly on the distance of the eggs from the fruit and the ease with which the larvæ find their ultimate object. Normally the early-season eggs are deposited upon the whorl of leaves about the fruit, while later in the year many eggs are laid directly on the fruit. It has been observed that some larvæ spend considerable time before they reach the fruit and that these satisfy their appetites on the foliage during the interim.

Upon reaching the fruit, the larvæ seek a place of entrance, as through the calyx, side, or stem. (See Pl. VI, A.) Some individuals crawl over the fruit for some little time before making an attack, while others proceed to enter with little hesitation. The larvæ will frequently take advantage of depressions or ruptures in the skin, as frost pits, hail marks, or injury from other causes.

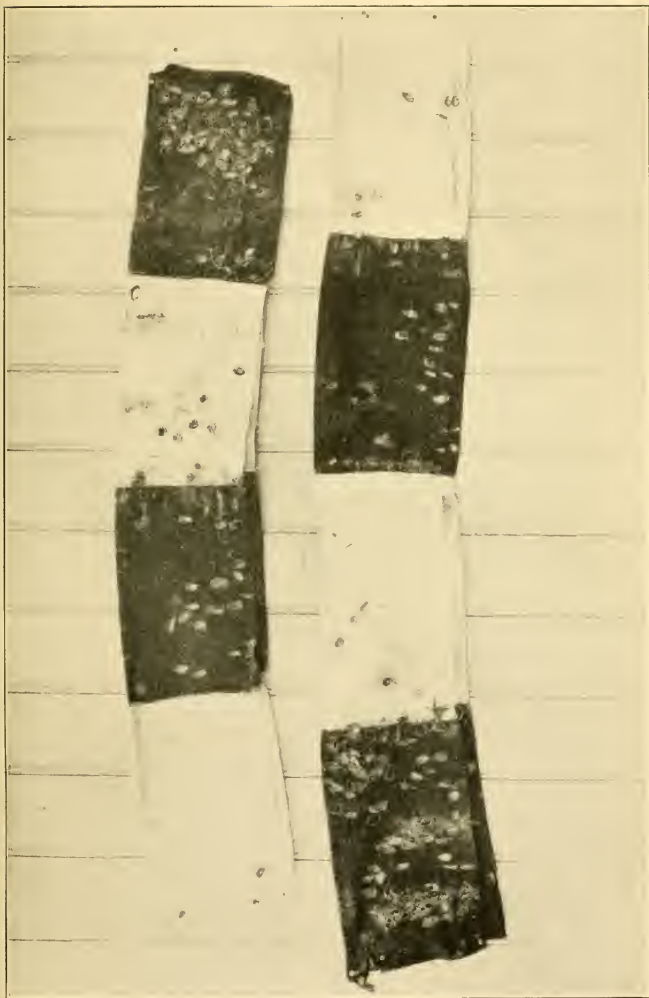
The larvæ, in starting to feed, tear away the skin by means of their mandibles and cast most of it aside, consuming very little. They first work directly beneath the skin, forming a shallow excavation just large enough to accommodate them, and at the same time, plug their entrance with frass.

THE CODLING-MOTH "STING."

The so-called "sting" is caused by the larvæ that succumb to the poison before they are able to make more than the shallow excavation above referred to. They sometimes die from natural causes after having penetrated beneath the skin and occasionally they leave an entrance hole to start a new one.

CODLING-MOTH LARVÆ FEEDING ON PEAR TWIGS.

On June 24, 1915, an examination of a pear orchard was made to determine the cause of the browning of the leaves. At first sight the orchard appeared to be affected with pear blight, *Bacillus amylovorus* (Burrill) De Toni, but on closer inspection it was found that codling-moth larvæ were responsible for the injury. There was practically no fruit in the orchard, owing to the spring freezes, and, as a result, the larvæ burrowed into the terminal ends of the twigs to a



BLACK AND WHITE BANDS SHOWING THAT LARVÆ PREFER TO FORM COCOONS BENEATH THE BLACK CLOTH.
THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

distance of about three-fourths inch. In many of the burrows no larvæ were found, they evidently having decided to leave after they had consumed most of the softer tissue of the new growth. The larvæ found were in either the third or fourth instars. An attempt was made to rear some of these larvæ in pear twigs, but this was unsuccessful. Two of the larvæ obtained from the pear twigs, however, were transferred to apples on the date collected, June 24, and from these two moths were reared, one moth issuing on July 19 and the other on July 20.

EXPERIMENTS WITH BLACK AND WHITE BANDS.

In fruit districts where the codling moth is abundant, spraying is frequently supplemented with banding. With the banding method a strip of cloth is placed around the trunk of the tree and the codling-moth larvæ that form cocoons beneath the cloth are destroyed at intervals of about 10 days throughout the season. The question has frequently been asked whether dark-colored bands are more attractive as a place of concealment than bands of a light color. To determine this, an experiment was made in 1916 in which were used bands of cloth folded to three thicknesses, each alternate quarter of which was black and white. (See Pl. VII.) The trunks of 10 trees were first thoroughly scraped and were then encircled with bands of this description on July 5. The segments of the bands were arranged so that the white and black quarters alternated with the four quarters of the trunk. Thus on 5 trees there was a black segment on the northeast side of the tree, while on the 5 remaining trees there was a white segment covering this quarter. The bands were first examined for larvæ on July 8 and every 3 days thereafter to August 19, inclusive. The results of this study are given in Table LXXIX, in which it will be seen that the codling-moth larva is strongly inclined, when the opportunity is present, to spin its cocoon beneath dark-colored cloth. Out of a total of 2,362 larvæ collected, 2,083, or 88.19 per cent, spun their cocoons beneath the black segments of the bands. A summary of this table is given in Table LXXX, which shows the number of larvæ collected under each segment. According to these figures, the codling-moth larvæ, with one exception, preferred the northern exposure of the tree trunk.

TABLE LXXIX.—*Experiments with black and white bands for the codling moth, Grand Junction, Colo., 1916.*

Tree No.	Color of band section and location on tree trunk.	Number of larvæ collected beneath band sections.																Total number of larvæ.	
		July 8.	July 11.	July 14.	July 17.	July 20.	July 23.	July 26.	July 29.	Aug. 1.	Aug. 4.	Aug. 7.	Aug. 10.	Aug. 13.	Aug. 16.	Aug. 19.	Black band section.	White band section.	
1	Black, N. E.	4	3	9	18	20	36	22	14	7	12	6	6	6	2	3	168	.....	
	White, S. E.	0	2	0	0	0	2	4	1	0	3	0	0	0	0	0	.....	12	
	Black, S. W.	1	2	6	14	16	29	10	6	4	4	2	0	2	2	4	102	.....	
	White, N. W.	0	0	0	0	1	2	0	0	1	0	1	0	0	1	0	.....	6	
2	White, N. E.	1	1	1	1	3	2	1	0	0	0	1	0	1	0	0	.....	12	
	Black, S. E.	3	5	4	12	12	18	16	5	7	10	4	1	4	2	2	105	.....	
	White, S. W.	0	0	1	0	0	1	1	1	0	1	1	0	0	0	0	.....	6	
	Black, N. W.	6	9	12	14	19	14	15	7	4	6	2	7	5	7	3	130	.....	
3	Black, N. E.	2	3	5	6	7	12	8	2	6	3	10	4	5	5	7	85	.....	
	White, S. E.	0	0	0	0	1	3	3	1	0	0	0	0	2	0	1	.....	11	
	Black, S. W.	3	0	6	1	13	4	4	3	4	3	3	2	3	4	3	56	.....	
	White, N. W.	1	0	2	2	3	1	1	1	1	0	0	2	4	5	4	.....	27	
4	White, N. E.	2	2	0	0	1	0	0	0	0	1	1	0	1	1	1	.....	10	
	Black, S. E.	0	1	6	5	2	9	5	1	4	4	2	3	6	1	7	56	.....	
	White, S. W.	1	0	0	0	2	1	1	0	0	2	4	2	3	5	0	.....	21	
	Black, N. W.	10	12	10	7	21	15	10	11	14	7	7	9	2	2	7	144	.....	
5	Black, N. E.	5	7	7	2	3	15	7	8	5	8	6	6	1	2	0	82	.....	
	White, S. E.	1	1	0	0	0	1	2	0	1	4	0	0	1	1	1	.....	13	
	Black, S. W.	0	2	2	1	7	3	7	3	3	0	3	2	1	1	4	39	.....	
	White, N. W.	0	0	2	0	1	3	0	0	0	1	0	1	3	0	1	.....	12	
6	White, N. E.	0	0	2	0	4	2	5	0	2	3	6	0	1	0	0	.....	25	
	Black, S. E.	5	3	2	5	12	9	6	4	2	5	0	1	1	1	1	57	.....	
	White, S. W.	0	0	0	0	0	1	3	2	0	0	1	0	0	0	1	.....	8	
	Black, N. W.	21	11	20	12	27	26	25	5	7	15	4	5	4	3	2	187	.....	
7	Black, N. E.	3	1	7	5	8	10	11	8	17	4	6	13	4	9	3	109	.....	
	White, S. E.	1	0	1	0	0	0	0	2	1	1	1	0	3	1	0	.....	11	
	Black, S. W.	0	0	4	2	6	5	3	2	2	4	1	1	4	4	2	40	.....	
	White, N. W.	1	1	0	0	1	5	2	0	1	5	4	0	3	4	0	.....	27	
8	White, N. E.	0	0	1	0	0	0	0	1	0	1	0	0	0	0	1	.....	6	
	Black, S. E.	3	2	10	5	10	10	9	4	8	3	0	1	2	3	0	70	.....	
	White, S. W.	1	0	0	0	0	1	1	2	0	1	0	0	3	1	4	.....	14	
	Black, N. W.	6	11	21	11	20	21	27	4	7	9	8	3	6	13	4	171	.....	
9	Black, N. E.	3	3	11	9	20	24	15	14	14	7	9	15	7	7	8	166	.....	
	White, S. E.	0	0	0	2	1	6	4	0	3	3	7	6	4	4	1	.....	41	
	Black, S. W.	0	2	15	12	13	25	19	8	2	3	2	9	5	7	4	126	.....	
	White, N. W.	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	.....	3	
10	White, N. E.	0	0	1	1	1	1	0	2	1	0	0	0	2	0	0	.....	8	
	Black, S. E.	8	3	3	10	13	3	6	3	2	1	1	2	0	3	1	59	.....	
	White, S. W.	0	0	0	1	0	0	1	0	0	0	0	0	0	0	4	.....	6	
	Black, N. W.	10	9	11	16	13	17	19	5	3	4	7	6	2	5	4	131	.....	
Total larvæ		102	97	182	174	281	337	275	129	132	139	110	107	101	107	89	2,083	279	

TABLE LXXX.—*Experiments with black and white bands for the codling moth, Grand Junction, Colo., 1916; summary of Table LXXIX.*

Color of band section and location on tree trunk.	Total number of larvæ collected.	Per cent of total number of larvæ.	Color of band section and location on tree trunk.	Total number of larvæ collected.	Per cent of total number of larvæ.
Black, N. E.	610	25.83	White, N. E.	61	2.58
Black, S. E.	347	14.69	White, S. E.	88	3.72
Black, S. W.	363	15.37	White, S. W.	55	2.33
Black, N. W.	763	32.30	White, N. W.	75	3.18
Total.....	2,083	88.19	Total.....	279	11.81

This experiment merely indicates that the codling-moth larva prefers a dark cocooning place. It should not be inferred that light-colored bands are of no value, since it is entirely possible that if the codling-moth larva has no better place to cocoon, it will be content to spin beneath bands of a light color. In orchard practice, burlap-

cloth bands, folded to two or three thicknesses, are very satisfactory for banding purposes.

PERCENTAGE OF TRANSFORMING AND WINTERING LARVÆ.

Season of 1915.—By reference to Table LXXXI it will be seen that 432 larvæ, or 47.52 per cent, of the first-brood larvæ that were reared in the insectary, transformed in 1915 to form the second brood; the remainder, 477, or 52.48 per cent, wintered. Out of 1,858 larvæ of the second brood, 20, or 1.08 per cent, transformed to form a third brood and the remainder, 1,838 larvæ, or 98.92 per cent, wintered. As previously mentioned, in the Grand Valley none of the third-brood larvæ transform until the spring of the next year.

TABLE LXXXI.—Percentage of codling moth larvæ wintering, Grand Junction, Colo., 1915.

Brood.	Number of larvæ—			Per cent transforming in 1915.	Per cent wintering.
	Leaving fruit.	Transforming in 1915.	Wintering.		
First.	909	432	477	47.52	52.48
Second.	1,858	20	1,838	1.08	98.92

Season of 1916.—The percentage of transforming and wintering larvæ of the first, second, and third broods reared in the insectary is given in Table LXXXII. As shown therein, 766 larvæ, or 74.15 per cent, of the first brood transformed; 267 larvæ, or 25.85 per cent, wintered. With the second brood, 170 larvæ, or 6.71 per cent, transformed and 2,362 larvæ, or 93.29 per cent, wintered. There were 328 third-brood larvæ, all of which wintered.

TABLE LXXXII.—Percentage of codling moth larvæ wintering, Grand Junction, Colo., 1916.

Brood.	Number of larvæ—			Per cent transforming in 1916.	Per cent wintering.
	Leaving fruit.	Transforming in 1916.	Wintering.		
First.	1,033	766	267	74.15	25.85
Second.	2,532	170	2,362	6.71	93.29
Third.	328	0	328	0.00	100.00

LASPEYRESIA POMONELLA (L.) VAR. SIMPSONII (BUSCK).

During the course of the codling-moth studies, the light buff colored variety of the codling moth known as *Laspeyresia pomonella* (L.) var. *simpsonii* (Busck) was bred from material collected in the field.

REVIEW OF SEASONAL-HISTORY STUDIES OF THE CODLING MOTH IN 1915 AND 1916.

A generalized review of the seasonal-history studies of the codling moth is given graphically in figures 17 and 36 for the seasons of 1915 and 1916 respectively. The curves represent approximately the beginning, ending, and crest of activity of the more important biological stages of the insect.

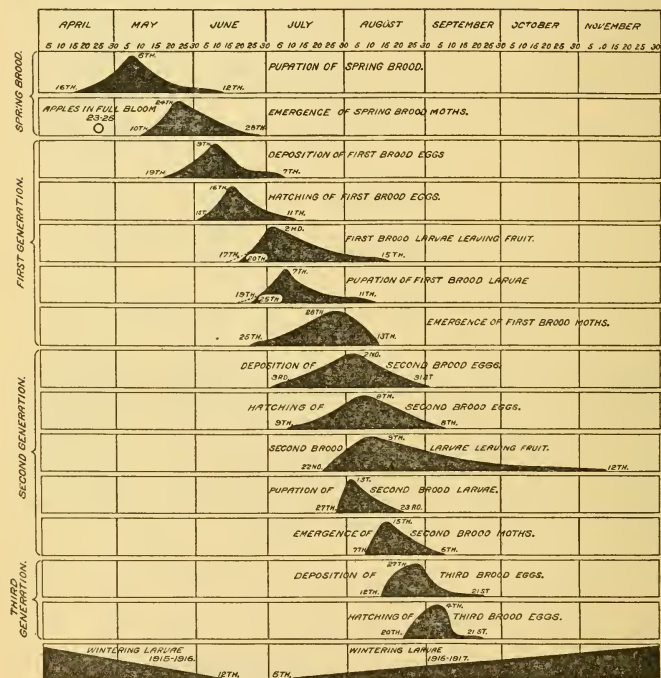


FIG. 36.—Diagram of life history of the codling moth in the Grand Valley of Colorado, 1916.

Pupation of spring brood.—In 1915 pupation commenced April 14, reached its maximum May 12, and ended June 8; in 1916 the earliest pupation took place April 16, was at its height May 6, and ceased June 12.

Emergence of spring-brood moths.—The first moth of the spring brood (1915) emerged May 12, the maximum emergence occurred May 24, and the last moth of this brood issued June 29. In 1916 the first spring-brood moth appeared May 10, the maximum emergence took place May 24, and the last moth issued June 28.

Deposition of first-brood eggs.—The spring-brood moths just referred to were employed in the oviposition studies. The earliest deposition of eggs of the first brood in 1915 occurred May 15, the greatest number of eggs was deposited on June 10, while the last egg was laid July 8. In the following year, the first eggs were deposited May 19, the crest of deposition was reached June 9, and the oviposition period ended July 7.

Hatching of first-brood eggs.—Hatching of first-brood eggs began in 1915 on May 27, and the eggs were hatching in largest numbers June 17. The last of the eggs hatched July 13. Hatching of first-brood eggs the next year commenced June 1, and on June 16 the eggs were hatching in maximum numbers, while the last of the eggs hatched on July 11.

First-brood larvæ leaving the fruit.—The time of larvæ leaving the fruit refers only to the insectary-reared individuals. In 1915 the first of these larvæ left the fruit June 21, on July 20 the largest number of larvæ made their exit from the apples, and on August 10 the last first-brood larva completed its feeding. According to the observations in the field, the first larvæ were collected in the Edwards orchard June 22 and in the Hamilton orchard June 28. In 1916 the first of the insectary-reared larvæ left the fruit June 20, the largest number left the fruit on July 2, and the last larva of this brood left the fruit August 15. But in the field the larvæ left the fruit at least three days earlier as shown by collections made in the Edwards and Hamilton orchards on June 17.

Pupation of first-brood larvæ.—The time of pupation of the first-brood insectary-reared larvæ in 1915 was as follows: First pupation June 27, maximum pupation July 6, last pupation August 4; in 1916 the first pupation took place June 25, the maximum pupation occurred July 7, and the last larva transformed on August 11.

Emergence of first-brood moths.—The time of emergence of first-brood moths as indicated in the diagrams refers to the moths that transformed from the field-collected larvæ. In 1915 the first moths of this brood (Hamilton orchard material) issued July 10, the maximum emergence occurred August 9, and the theoretical limit of emergence was August 19. In the following year all of the moths from the transforming larvæ collected in the Hamilton and Edwards orchards were used for oviposition purposes. The first of these moths issued June 25, the maximum emergence occurred July 28, and the theoretical limit of emergence was August 13.

Deposition of second-brood eggs.—Eggs of the second brood were first deposited in 1915 on July 12, on August 14 they were laid in maximum numbers, and on September 15 the last eggs were deposited. In 1916 the earliest deposition occurred July 3, the maxi-

imum deposition on August 2, and the deposition period ended August 31.

Hatching of second-brood eggs.—Eggs of the second brood (1915) commenced hatching July 19 and were hatching in maximum numbers August 21. The last eggs of this brood hatched September 24. In the following year the first eggs hatched July 9, and the largest number August 8. The hatching of this brood of eggs ceased September 8.

Second-brood larvæ leaving the fruit.—The data for these curves were taken from insectary-reared larvæ, and as shown in the graph the first larvæ left the fruit in 1915 on August 5. The larvæ left the fruit in largest numbers September 1, while the last larva of this brood completed its feeding period November 11. In 1916 the first larva emerged from the fruit July 22, on August 9 they left the fruit in maximum numbers, and the last larva of this brood made its exit from the fruit on November 12.

Pupation of second-brood larvæ.—Larvæ of the second brood (1915) began to pupate August 12. The last transformation took place October 2. In the succeeding year the pupation was as follows: First July 27, maximum August 1, last August 23.

Emergence of second-brood moths.—According to the insectary-reared material of 1915, the moths of the second brood commenced to issue August 23. The emergence ended October 14. During the season of 1916 the emergence period extended from August 7 to September 6, with the maximum of emergence occurring August 14.

Deposition of third-brood eggs.—The eggs of the third brood deposited in 1915 failed to hatch. The first egg was laid September 16, the last September 23. In 1916, however, fertile eggs were deposited, the oviposition period extending from August 12 to September 21 with the maximum deposition August 27.

Hatching of third-brood eggs.—None of the third-brood eggs from insectary-reared material hatched in 1915. In the following year the hatching period commenced August 20 and ended September 21. On September 4 the third-brood eggs hatched in greatest numbers.

Wintering larvæ.—The last of the wintering larvæ of the season of 1914 pupated June 8, 1915. The first larva taken in the field during the season of 1915 to pass the winter successfully and transform the following year to the adult stage was collected July 11 in the Edwards orchard. In 1916 the last wintering individual pupated June 12. Since no observations of the time of emergence of moths were taken in 1917, it is impossible to state just when the first wintering larvæ appeared in 1916. The part of the graph referring to the wintering larvæ of 1915–16 should be considered as an approximate estimate only.

SUMMARY.

The life-history studies recorded herein were made in the Grand Valley of Colorado during the seasons of 1915 and 1916.

The climate of the Grand Valley is comparatively dry and warm during the summer season, and is very favorable to the development of the codling moth.

According to the data secured in these studies, there are two complete generations and a partial third generation of the codling moth in the Grand Valley.

Length of the pupal stage of the spring brood.—In 1915 the length of the pupal stage of the spring brood averaged 27.58 days, the maximum was 34 days, and the minimum 15. In 1916 the average was 26.80 days, the maximum 36, and the minimum 13.

Oviposition by moths of the spring brood.—In 1915 the average number of days before oviposition was 6.19, the maximum 19, and the minimum 2; the average number of days for the period of oviposition was 13.82, the maximum 33, and the minimum 1; the average number of days from the date of emergence to the date of last oviposition was 19.14, the maximum 37, and the minimum 5. In 1916 the average number of days before oviposition was 6.07, the maximum 13, and the minimum 2; the average number of days for the period of oviposition was 13.38, the maximum 32, and the minimum 1; the average number of days from the date of emergence to the last oviposition was 18.46, the maximum 34, and the minimum 7.

Number of eggs per female moth of the spring brood.—According to the oviposition studies of the spring-brood moths of 1915, the average number of eggs per female moth was 12.59; in 1916, 11.34 eggs.

Length of life of moths of the spring brood.—In 1915 the average length of life of the male moths was 14.59 days and of the female moths 15.86 days; the maximum length of life of the male moths was 36 days and of the female moths 39 days; the minimum length of life of the male moths was 1 day and of the female moths 1 day. In 1916 the average length of life of the male moths was 14.67 days and of the female moths 15.73 days; the maximum length of life of the male moths was 35 days and of the female moths 39 days; the minimum length of life of the male moths was 1 day and of the female moths 1 day.

THE FIRST GENERATION.

Embryological changes and length of the incubation period of first-brood eggs.—The embryological changes in the eggs of the first brood and the length of the incubation period were as follows: In 1915 the average number of days from the date of egg deposition

to the time of the appearance of the red ring was 2.70, the maximum 9, and the minimum 1; the average number of days from the date of deposition to the black-spot stage was 6.62, the maximum 13, and the minimum 4; the average incubation period was 9.14 days, the maximum 15, and the minimum 6. In 1916 the average number of days from the date of deposition to the appearance of the red ring was 2.62, the maximum 10, and the minimum 1; the average appearance of the black spot from the time of egg deposition was 6.68 days, the maximum 11, and the minimum 5; the average incubation period was 7.32 days, the maximum 14, and the minimum 6.

Length of feeding period of the first-brood larvæ, stock-jar method.—During the season of 1915, the length of the feeding period averaged 21.64 days, the maximum was 35, and the minimum 12. In the following year the average length of the feeding period was 20.19 days, the maximum 42, and the minimum 14.

Length of feeding period of the first-brood larvæ, bagged-fruit method.—The records in 1915 give an average feeding period of 22.77 days, a maximum of 35, and a minimum of 15. In 1916 the average feeding period was 21.10 days, the maximum 29, and the minimum 17.

Length of cocooning period of larvæ of the first brood.—As shown by the observations in 1915, the average cocooning period was 6.70 days, the maximum 28, and the minimum 1. In the following season the average cocooning period was 5.53 days, the maximum 30, and the minimum 2.

Length of pupal stage of the first brood.—The average length of the pupal stage, first brood, in 1915 was 11.44 days, the maximum 31, and the minimum 6; in the succeeding year the average length was 11.23 days, the maximum 19, and the minimum 6.

Oviposition by moths of the first brood.—As shown by the studies in 1915, the average number of days before oviposition was 2.07, the maximum 5, and the minimum 1; the average number of days from the first to the last oviposition was 16.78, the maximum 25, and the minimum 7; the average number of days from date of emergence to last oviposition was 17.85, the maximum 26, and the minimum 10. The summarized data for 1916 are as follows: The average number of days from the date of emergence to the first oviposition was 2.21, the maximum 5, and the minimum 1; the average number of days from the first to the last oviposition was 12.69, the maximum 20, and the minimum 1; the average number of days from the time of emergence to the last oviposition was 13.63, the maximum 20, and the minimum 5.

Number of eggs per female moth of the first brood.—The moths of the first brood of 1915 deposited 46.73 eggs per female moth. In the following year the female moths deposited an average of 43.98 eggs.

Length of life of moths of the first brood.—In 1915 the average length of life of the male moths was 11.86 days, the maximum 41, and the minimum 1; the average life of the female moths was 12.68 days, the maximum 35, and minimum 1. In 1916 the summarized figures give 13.12 and 12.20 days as the average length of life of the male and female moths respectively. The maximum life of the male moths was 38 days and of the female 26 days; the minimum length of life of both the male and female moths was 1 day.

Life cycle of the first generation.—The average life cycle as obtained by rearing individuals from the egg to the adult stage, stock-jar feeding method, in 1915 was 49.30 days, the maximum 72, and the minimum 38. According to the bagged-fruit feeding method, the average life cycle was 49.18 days, the maximum 74, and the minimum 36. To obtain the complete life-cycle add 2.07 days, which was the average time from the emergence of the moths to the deposition of the first egg. In 1916 the average life cycle, stock-jar feeding method, was 44.89 days, the maximum 77, and minimum 36; and the average complete life cycle, obtained by adding 2.21 days to the life cycle, was 47.10 days. The average life cycle, bagged-fruit feeding method, was 46.37 days, the maximum 66, and minimum 38. The average complete life cycle was 48.58 days.

THE SECOND GENERATION

Embryological changes and length of the incubation period of second-brood eggs.—In 1915 the average number of days from the deposition of the egg to the appearance of the red ring was 1.85, the maximum 4, and the minimum 1; the average time for the appearance of the black spot was 5.54 days, the maximum 8, and minimum 3; the average incubation period was 7.22 days, the maximum 11, and minimum 6. In the next year the average appearance of the red-ring stage was 2.06 days after egg deposition, the maximum 3, and minimum 1. The average appearance of the black spot was 5.80 days, the maximum 7, and minimum 5. The length of the incubation period averaged 6.93 days, the maximum 10, and minimum 6.

Length of feeding period of second-brood larva.—The average length of the feeding period in 1915 was 28.69 days, maximum 67, and the minimum 15. In 1916 the average length of the feeding period was 28.61 days, the maximum 70, and the minimum 14.

Length of cocooning period of larvæ of second brood.—In 1915 the average length of the cocooning period was 9.35 days, the maximum 31, and minimum 3. In the following year the average number of days for the construction of the cocoon was 4.80, the maximum 14, and minimum 2.

Length of pupal stage of second brood.—The average length of the pupal stage of the pupæ of the second brood in 1915 was 15.62 days, the maximum 31, and the minimum 11. In 1916 the average length of the pupal stage was 13.51 days, the maximum 16, and the minimum 11.

Oviposition by moths of the second brood.—No oviposition data were obtained in 1915 owing to the fact that the eggs deposited by the moths of the second brood failed to hatch. In 1916 fertile eggs were deposited, but since moths emerging on different dates were confined in the same cages no oviposition data were obtained.

Number of eggs per female moth of the second brood.—In 1915 no fertile eggs were deposited, but in the following year the average number of eggs per female moth was 45.58.

Length of life of moths of the second brood.—The moths of the second brood of the seasons of 1915 and 1916 were not confined in separate cages according to their time of emergence. For this reason no data were obtained.

Life cycle of the second generation.—The life cycle of the second generation in 1915, as determined by rearing, was as follows: Average length of incubation period 6.12 days, average larval feeding period 20.49 days, average cocooning period 8.56 days, average pupal period 15.62 days, and average life cycle 50.81 days. In 1916 the records show that the average length of the incubation period was 6.01 days, the average larval feeding period 18.08 days, the average cocooning period 4.78 days, the average pupal period 13.52 days, and the average life cycle 42.40 days.

THE THIRD GENERATION.

Embryological changes and length of the incubation period of third-brood eggs.—In 1916 the average number of days from the date of deposition to the appearance of the red ring was 2.49, the maximum 5, and the minimum 2; the average number of days from the date of deposition to the appearance of the black spot was 6.36, the maximum 9, and the minimum 6; the average incubation period was 7.77 days, the maximum 11, and the minimum 7.

Length of feeding period of third-brood larvæ.—The average larval feeding period of the third-brood larvæ in 1916 was 37.55 days, the maximum 68, and the minimum 20.

PERCENTAGE OF TRANSFORMING LARVÆ.

Percentage of transforming larvæ of the first brood.—In 1915 47.52 per cent of the first-brood larvæ transformed, while in the following season 74.15 per cent pupated.

Percentage of transforming larvæ of the second brood.—In 1915 1.08 per cent of the second-brood larvæ transformed. In 1916 6.71 per cent of these larvæ transformed.

Percentage of transforming larvæ, band material.—In 1915 the percentage of larvæ collected in the field in connection with the band studies that transformed to the adult stage was 45.37, and in 1916 40.88.

MISCELLANEOUS.

Natural enemies.—The following predators were recorded: A small beetle, *Tenebroides corticalis* Melsh., and a spider, *Coriarachne versicolor* Keys.

The following parasites were observed: *Trichogramma minutum* Riley, *Dibrachys clisiocampae* Fitch, and *Arthrolytus apatela* Ashmead. The predacious and parasitic enemies play a very unimportant rôle in checking the codling moth in the Grand Valley.

The emergence of moths from fruit cellars is later than that in the field. The period of emergence in fruit cellars, however, is shorter than that which obtains under field conditions.

The majority of the moths of the spring and first broods emerge during the latter part of the morning and early part of the afternoon.

The codling moth is believed to be a nonmigratory species except for short local flights. The moths have, however, strength to fly in a continuous flight, unaided by the wind, for a distance of at least one-half mile.

The codling moth is most active in depositing her eggs late in the afternoon to early in the evening, the activity being greatest just about dusk.

The fecundity of the codling moth in the Grand Valley is high. Three female moths of the first brood deposited in confinement over 300 eggs each, the highest total deposition by one moth being 316 eggs, 115 being the largest number deposited in one day by a single female.

The codling moth larva normally cuts its way through the eggshell and emerges head first. Occasionally it will protrude the anal end first, but in this case it is sometimes unable to extricate itself.

An examination of a pear orchard devoid of fruit revealed the fact that codling moth larvæ will sometimes burrow into the new growth, resulting in the browning of the foliage.

The codling moth larva prefers to spin up under dark-colored bands.

The buff-colored variety of the codling moth known as *Laspeyresia pomonella* (L.) var. *simpsonii* (Busck) was reared in the Grand Valley.

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EFFECTS OF NICOTINE SULPHATE AS AN OVICIDE AND LARVICIDE ON THE CODLING MOTH AND THREE OTHER INSECTS.

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INTRODUCTION.

For several years nicotine and its compounds have been used against certain soft-bodied insects as contact insecticides, and within the past few years the question has been raised concerning the effects of nicotine sulphate upon the eggs and early instars of other insects which are commonly controlled by other means.

During 1915 and 1916, in the State of Washington, De Sellem (1)² carried on field experiments with nicotine sulphate and arsenate of lead and claimed that the former insecticide was as efficient as the latter one for controlling the codling moth (*Laspeyresia pomonella* L.). During the season of 1917 similar experiments in three orchards were performed by the same author and others (2) on a larger scale in the same State, and the results obtained showed that nicotine

¹ Resigned March 31, 1920.

² Numbers (italic) in parentheses refer to "Literature cited," p. 18.

sulphate did not control the codling moth as well as did lead arsenate, and that its control was unsatisfactory on all of the plats sprayed, except one. The Bureau of Entomology also conducted some field experiments during the season of 1917 in three important apple regions in the United States, the first of these being in the Lake region at Benton Harbor, Mich.; the second one in the mountainous region at Grand Junction, Colo.; and the third one in the semiarid region at Roswell, N. Mex. In the first region the experiments were carried on by Mr. Simanton; in the second one by Mr. Plank; and in the third one by Mr. Fiske. All of the laboratory experiments were performed by Dr. McIndoo.

Lovett (5) reports that nicotine sulphate with soap is an effective ovicide for the codling moth. Excepting this experiment, in which only 26 codling-moth eggs were used, no other experiments, either in orchards or in a laboratory, have ever been conducted to determine how nicotine sulphate checks the work of the codling moth, although Feytaud (3), testing the effects of pure nicotine and soap in the laboratory upon the eggs of two moths belonging to the same family, ascertained that about 75 per cent of the embryos in the eggs tested were aborted during the last stage of development, while the remaining eggs hatched.

The first portion of the present paper embodies the results obtained in the laboratory concerning the effects of nicotine sulphate as an ovicide and larvicide on the codling moth and three other insects. The second portion of this study deals with the effectiveness of nicotine sulphate as compared with the efficiency of arsenate of lead for controlling the codling moth in orchards.

EXPERIMENTS CONDUCTED IN THE LABORATORY.

In order to throw some light on how nicotine sulphate checks the work of the codling moth the following tests were performed:

EFFECTS OF NICOTINE SULPHATE² ON EGGS AND NEWLY HATCHED LARVÆ OF THE SILKWORM MOTH.

This investigation was begun in September, 1916, when it was too late to obtain codling-moth eggs or fresh eggs of any other insect; so the study was begun by using eggs of the silkworm moth (*Bombyx mori* L.), 10,000 of which were 14 months old, 2,000 of which were from 1 to 6 days old, and 10,000 of which were 3 months old.

EFFECTS OF NICOTINE SULPHATE ON EGGS OF THE SILKWORM MOTH.

The eggs just enumerated were divided into several lots, and some of these lots were sprayed with nicotine sulphate (1:800 + fish-oil

² Throughout this paper reference is made to "nicotine sulphate" containing 40 per cent of nicotine.

soap, 2 pounds to 100 gallons of water) ; some with nicotine sulphate 1:800; some with nicotine sulphate 1:1,066; and others were not sprayed, these being used as controls. During October, 1916, all of the eggs 14 months old hatched, but the hatching of the sprayed ones was more or less retarded. Relative to the eggs from 1 to 6 days old when treated, the following data were obtained during the spring of 1917. Only 1 per cent of those sprayed with nicotine sulphate 1:800 hatched, while 80 per cent of the unsprayed ones hatched; in regard to the eggs 3 months old, 20 per cent of those sprayed with nicotine sulphate 1:800+soap hatched, 25 per cent of those sprayed with nicotine sulphate 1:800 hatched; 35 per cent of those sprayed with nicotine sulphate 1:1,066 hatched; while 90 per cent of those unsprayed hatched. The unsprayed eggs hatched quickly, and the newly hatched larvæ grew normally, while the sprayed eggs were more or less retarded in hatching and the young larvæ were so stunted that after 20 days the larvæ from the unsprayed eggs were from 1 to 6 times as large as those from the sprayed eggs. A large percentage of the unhatched eggs contained embryos aborted during the last stage of development.

EFFECTS OF NICOTINE ON NEWLY HATCHED SILKWORMS.

McIndoo (6, p. 97) has already shown that the exhalation (called odor) from leaves an hour after having been sprayed with a solution of nicotine sulphate kills small fall webworms (*Hyphantria cunea* Dru.), small caterpillars of the catalpa sphinx (*Ceratomia catalpæ* Bdv.), and certain aphids (*Aphis populifoliae* Davis).

On May 12 at 12.30 p. m. a bunch of leaves on a mulberry tree was dipped into a solution of nicotine sulphate 1:400 and another bunch into a solution 1:800. On May 14 at 9.30 a. m. a leaf was removed from each bunch of the leaves treated, and 20 silkworms 1 day old were placed on each leaf; at 12.30 p. m. all the worms were dead. The leaves still emitted a faint odor like that from the solution. On May 16 at 11.15 a. m. the preceding experiment was repeated: on May 17 at 9 a. m. 8 worms on the leaf treated with the solution 1:400 and 1 on the other leaf were dead; all of the remaining live worms were more or less stupid, and two hours later, after having been fed with a fresh leaf treated with the solution 1:400, died. This leaf was cut into small pieces, and it still emitted a very faint odor like that from the solution, but the leaves treated with the solution 1:800 had ceased to emit this odor so far as the observer could perceive. At no time during any of the preceding experiments did the silkworms eat the treated leaves; the exhalation arising from them therefore must have killed the worms.

EFFECTS OF NICOTINE SULPHATE ON EGGS AND NEWLY HATCHED LARVÆ OF THE CODLING MOTH.

In tests with the eggs and newly hatched larvæ of the silkworm moth it was determined that nicotine sulphate is efficient against only the fresh eggs, but more or less retards the hatching of older eggs. The exhalation from leaves which had been dipped into solutions of nicotine sulphate from 1 to 5 days previously killed newly hatched silkworms, and from the sixth to the eleventh day after the foliage had been treated the newly hatched silkworms, after having eaten some of these treated leaves, died, the mortality varying from a high percentage on the sixth day to no mortality on the tenth and eleventh days. The following pages give the results obtained by using the eggs and newly hatched larvæ of the codling moth:

EFFECTS OF NICOTINE SULPHATE ON EGGS OF THE CODLING MOTH IN THE LABORATORY.

Many codling-moth sticks containing wintering larvæ, reared at the bureau's field station in Grand Junction, Colo., were shipped to Washington, D. C., where they were kept out of doors until March 1, 1917; after this date they were kept in a refrigerator, and at irregular periods about 40 of them at a time were removed from the refrigerator and were placed in battery jars, which were covered with cheesecloth. Each morning the moths that had emerged were removed to other battery jars containing moist sand and either glass plates or foliage of fruit trees. In these jars the moths copulated and the females laid their eggs on the glass plates and foliage, which after being removed were then sprayed. By this method eggs of a known age were easily obtained.

Since these experiments were started in March, when fruit-tree foliage was not to be had, glass plates were put in the battery jars, and whenever a sufficient number of eggs had been deposited on these plates, the latter were removed, sprayed, and then placed in other battery jars also containing moist sand.

Since the details of the four experiments performed, using eggs on glass plates, are similar, only Experiment No. 1 will be described fully. On April 4 the first plate, bearing 57 eggs (1 and 2 days old), was sprayed with a solution of nicotine sulphate 1:400; the second plate, bearing 20 eggs, with a solution 1:800; and a third plate, bearing 16 eggs, was used as a control. Each plate was put in a separate battery jar. On April 7 most of the eggs were in the red-ring stage; the sprayed plates bore spots or a thin film as a residue left after the evaporation of the solution, and these spots still emitted a nicotine-like odor. On April 11 many of the eggs were in the black-spot stage and the plates still emitted the nicotine-like odor; two small last year's apples were put in each jar. On

April 12 the eggs on each plate began to hatch, and later when examined 42.1 per cent of those on the first plate had hatched; 60 per cent of those on the second plate and 92.7 per cent of those not sprayed had hatched. On April 13 several dead larvæ were found on the sprayed plates and on the apples by these plates, but no dead ones were found in the jar containing the control plate, and four burrows were counted in the apple by this plate. On later dates it was common to see dead larvæ in each of the first two jars. On April 23 the plate sprayed with the solution 1:400 still emitted a faint nicotine-like odor. The apples by this plate showed four burrows, from which finally emerged two full-grown larvæ; those by the other sprayed plate only one burrow, from which emerged a larva; and those by the control plate also four burrows, from which emerged two large larvæ. Four of the five larvæ passed through the pupal stage and emerged as adult moths, while the fifth one only reached the pupal stage; this one was from the first two apples mentioned.

The preceding tests indicate that nicotine sulphate is not an efficient ovicide against the codling moth when the eggs are laid on glass plates. Other experiments were performed by constantly keeping fresh foliage of pear and apple trees in the battery jars. On the third day after applying the spray solution a nicotine-like odor was still emitted from the leaves, the strength of which depended upon the strength of the solution used. This odor gradually disappeared, and by the time the eggs began to hatch the observer could not perceive it. Unsprayed leaves usually have bright and shiny surfaces, but sprayed ones have dull surfaces, and with the aid of a hand lens a dried film of residue from the solution may often be seen on them. These experiments are summarized in Table I; experiments 1, 2, and 3 represent individual tests with eggs on pear-tree leaves, while experiment 4 is a summary of several tests with eggs on apple-tree leaves. Soap was used at the rate of 2 pounds per 100 gallons of water.

Relative to experiment 4, the following notes, although not significant, are nevertheless interesting. Four last year's apples, each being dipped into the same spray solution as that sprayed on the leaves, were placed in four jars containing the sprayed leaves. Two apples not sprayed were also placed in two jars containing unsprayed leaves. Eliminating one of the four jars and its contents on account of the apple in it becoming badly decayed before the eggs hatched, 245 eggs in the other three jars hatched and later 14 burrows were counted in the three remaining apples. In the two jars used as controls 52 eggs hatched, and later 14 burrows were also counted in the two apples contained therein. Soon after this date all of these apples totally decayed and consequently no matured larvæ were obtained from them.

Three apples, after having been dipped into a solution of nicotine sulphate 1:400+soap, were placed in three battery jars containing many unsprayed eggs. A later examination showed that 49 eggs had been deposited on the apples, 47 of which had hatched. These decayed apples contained 39 burrows, and finally two moths were found in each of two jars. A repetition of this experiment resulted in obtaining no moths from three dipped apples and only two from three control apples.

TABLE I.—*Effects of nicotine sulphate on codling-moth eggs (1 and 2 days old) laid on fruit-tree foliage in laboratory.*

Experiment No.	Strength of nicotine-sulphate solution used, and control.	Number of eggs sprayed.	Eggs hatched.	Embryos aborted.	Eggs totally undeveloped.
			<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1.....	1:400.....	15	53.3	46.7	.....
	1:800.....	33	66.7	33.3	.....
	1:800+soap.....	15	63.7	.....	36.3
	(Control.....	29	96.6	.....	3.4
2.....	1:1,000+soap.....	38	92.1	7.9	.....
	(Control.....	75	98.7	.....	1.3
3.....	1:800.....	52	63.5	13.4	23.1
	(Control.....	64	95.3	3.1	1.6
4.....	1:400.....	116	47.4	52.6	.....
	1:400+soap.....	158	49.2	47.4	3.4
	1:800+soap.....	213	79.8	20.2	.....
	(Control.....	56	94.4	.....	5.6

To test the value of nicotine sulphate as an ovicide for codling-moth eggs, two experiments were started by E. H. Siegler, entomological assistant, June 5, 1918, at the bureau's field laboratory in Wallingford, Conn. In each experiment the eggs were deposited on apple-tree foliage by moths confined in oviposition jars. All of the treated eggs were thoroughly immersed in a solution of nicotine sulphate 1:800 plus common laundry soap (3 pounds to 50 gallons of water). After treatment each leaf was placed in a separate jar, with an apple as food for the larvæ as they hatched.

Experiment No. 1.—In this experiment the eggs were deposited June 3, and at the time of dipping them into the spray solution many had advanced to the red-ring stage. Seven leaves bearing 310 eggs were treated, while one leaf bearing 190 eggs was left untreated as a check. The results obtained show that out of 310 eggs treated, 296, or 95.48 per cent, hatched; out of 190 untreated eggs 96.84 per cent hatched. Many of the larvæ entered the apples and commenced feeding vigorously therein.

Experiment No. 2.—The eggs employed in this test were deposited June 4, and at the time of dipping them into the nicotine-soap solution none had advanced to the red-ring stage. Out of a total of 37 eggs, 35, or 94.59 per cent, hatched; out of 11 untreated eggs, 11, or

100 per cent, hatched. As in experiment No. 1, many of the newly hatched larvæ entered the apples and started their development therein.

EFFECTS OF NICOTINE SULPHATE ON NEWLY HATCHED LARVÆ OF THE CODLING MOTH IN THE LABORATORY.

From the preceding results it is evident that nicotine sulphate is not an efficient ovicide against the codling moth; and since the eggs probably hatched after the cessation of an injurious exhalation from the sprayed glass plate and leaves, the newly hatched larvæ perhaps died of starvation, rather than from the spraying. To test the effects of the exhalation from leaves sprayed one or more days previously upon the newly hatched larvæ, the following experiments were performed:

At 11.30 a. m. a pear-tree leaf was dipped into a solution of nicotine sulphate 1: 400, and another one into a solution 1: 800. At 1.30 p. m., when the leaves were dry, 15 newly hatched codling-moth larvæ were placed upon each leaf. At 4.30 p. m. 13 larvæ were dead on the first leaf, but only 6 dead on the second leaf. The leaves still emitted a nicotine-like odor. The following morning all the larvæ were dead and the leaves were wilted. At no time did any of them try to burrow into the leaves as do larvæ on leaves not treated with these solutions, and they crawled away from these leaves more than do larvæ on untreated leaves.

On May 4 a twig bearing foliage on an apple tree was dipped into a solution of nicotine sulphate 1: 400, and another twig into a solution of 1: 800. On May 14 a leaf was removed from each twig and then 28 newly hatched codling-moth larvæ were placed upon each leaf between two watch glasses. During the first day the larvæ burrowed considerably in the leaves and apparently were not affected. During the second day three of them died, but the leaves began to wilt. During the third day all of them died, and by this time the leaves had become dry. Between May 4 and 14 there had been much rain and on the latter date the leaves did not emit a nicotine-like odor. This experiment shows that the exhalation from the treated leaves did not affect the larvæ and that in all probability all of them finally died of starvation.

On May 18 the two twigs mentioned in the foregoing paragraph were again dipped into solutions of the same strengths, but this time soap was added at the rate of 2 pounds per 100 gallons of water. On May 19 six newly hatched larvæ were placed on each of two detached leaves as usual. The leaves still emitted a faint odor resembling that from the solutions. No larvæ died that day and only 4 of the 12 were found dead the following day. The leaves were slightly eaten.

On May 20, at 1 p. m., or the second day after the leaves had been treated, 13 codling-moth larvæ were placed on each of two detached leaves: at 3 o'clock 6 silkworms (2 days old) were also placed on each leaf; at 4.30 o'clock 10 of the 12 silkworms were dead, but not one of the codling-moth larvæ had succumbed. The following morning all of the silkworms were dead, but only 12 of the 26 codling-moth larvæ had succumbed. The leaves were slightly eaten.

On the third day after the leaves had been treated the preceding experiments were repeated. On this date only a few of the silkworms and none of the codling-moth larvæ died. The following morning all of the silkworms were dead, but the codling-moth larvæ did not die till later, when the leaves began to dry.

On the tenth day after the leaves had been treated the codling-moth larvæ tested apparently were not affected.

On various dates many small pears (22 mm. in diameter) with the calyx cups yet open were picked and then sprayed with solutions of nicotine sulphate. Some of these solutions contained soap in the proportion of 2 pounds to 100 gallons of water. The stem of each pear used was inserted into a small bottle containing water. From one to seven days after the pears had been sprayed six active codling-moth larvæ were removed from the oviposition jars and then placed on each pear; unsprayed pears were used as controls.

A glance at Table II shows that about 75 per cent of the larvæ tested were killed when placed upon pears which had been sprayed one or two days previously. It is also seen that the mortality decreases to about 25 per cent on the sixth and seventh days.

TABLE II.—*Effects on newly hatched codling-moth larvæ when placed upon small pears previously sprayed with solutions of nicotine sulphate in laboratory.*

Number of days after spraying pears when larvæ were tested.	Solution 1:400		Solution 1:800.		Solution 1:400+soap.		Solution 1:800+soap.		Control.	
	Number of larvæ tested.	Larvæ found dead on pears.	Number of larvæ tested.	Larvæ found dead on pears.	Number of larvæ tested.	Larvæ found dead on pears.	Number of larvæ tested.	Larvæ found dead on pears.	Number of larvæ tested.	Larvæ found dead on pears.
		<i>Per cent.</i>		<i>Per cent.</i>		<i>Per cent.</i>		<i>Per cent.</i>		<i>Per cent.</i>
1.....	18	72.2	18	77.7	18	61.1	12	25.0	18	0.0
2.....	18	77.7	18	72.2	18	61.1	12	25.0	6	16.6
3.....	6	50.0	6	50.0	6	100.0	6	66.6	6	16.6
4.....	6	83.3	6	66.6	6	50.0	6	33.3	6	16.6
5.....	12	25.0	6	33.3	6	33.3	6	33.3	6	16.6
6.....	6	33.3	6	33.3	6	33.3	6	33.3	6	16.6
7.....	6	33.3	6	33.3	6	33.3	6	33.3	6	16.6

EFFECTS OF NICOTINE SULPHATE ON EGGS OF TWO OTHER INSECTS.

Experiments similar to those performed on the eggs of silkworm moths and codling moths were also conducted upon the eggs of

potato beetles (*Leptinotarsa decemlineata* L.) and tussock moths (*Heemerocampa leucostigma* S. & A.).

Fifteen potato-plant leaves, each bearing a cluster of potato-beetle eggs (1 and 2 days old), were collected in a potato patch, and after the petiole of each leaf had been inserted into a bottle of water in the laboratory, 11 of the leaves were sprayed with solutions of nicotine sulphate 1:400 and 1:800 and the other four leaves were used as controls. The eggs thereafter were observed daily; practically all of them hatched, and the newly hatched larvæ were apparently not affected by remaining on the wilted leaves 1 or 2 days, after which they thrived when fed fresh and unsprayed leaves. Relative to the time of hatching there seemed to be little, if any, difference between the sprayed and unsprayed eggs. Similar results were obtained by spraying eight clusters of potato-beetle eggs in a potato patch with a solution 1:400 containing soap (2 pounds to 100 gallons water).

In order to obtain tussock-moth eggs of known ages, many large caterpillars of this moth were collected and were put in wire-screen cages, in which the remainder of the life history was completed. On various dates eggs from these cages and some from trees in the field were collected, placed in open pasteboard boxes, and then sprayed with four solutions of nicotine sulphate. Two of the solutions contained soap in the proportion of 2 pounds per 100 gallons of water. Some of the control eggs were not sprayed, while the others were sprayed with tap water; no difference in hatching between these was observed. The details of these experiments are summarized in Table III:

TABLE III.—*Effects of nicotine sulphate on eggs of tussock moth in laboratory.*

Strength of nicotine-sulphate solution used, and control.	Eggs collected in cages.						Eggs collected in field. Age probably from freshly-laid eggs to those ready to hatch.		
	Eggs 1 and 2 days old.			Eggs 2 and 3 days old.			Number of egg masses tested.	Egg masses that hatched.	Egg masses that did not hatch.
	Number of egg masses tested.	Egg masses that hatched.	Egg masses that did not hatch.	Number of egg masses tested.	Egg masses that hatched.	Egg masses that did not hatch.			
		Per cent.	Per cent.		Per cent.	Per cent.		Per cent.	Per cent.
1:400.....	-----	-----	-----	4	25.0	75.0	12	83.3	16.7
1:800.....	-----	-----	-----	4	62.5	37.5	-----	-----	-----
1:800+soap.....	4	25.0	75.0	4	25.0	75.0	33	87.9	12.1
1:1000+soap.....	4	37.5	62.5	-----	-----	-----	45	82.2	17.8
Control.....	3	83.4	16.6	4	87.5	12.5	45	93.3	6.7

It is seen from Table III that nicotine sulphate is not efficient against the eggs of the tussock moth; the percentages given for the masses of eggs that did not hatch, however, are too low, because the final examination showed that as a rule when a control and a sprayed

mass of eggs (both recorded as hatched) were closely observed, more larvæ had emerged from the former than from the latter. The ones sprayed with nicotine sulphate were slightly retarded in hatching, and the eggs in most of the masses which did not hatch contained aborted embryos, while the remainder of them were totally undeveloped.

DISCUSSION AS TO HOW NICOTINE SULPHATE ACTS AS AN OVICIDE AND LARVICIDE.

It is difficult to determine accurately how any insecticide kills a larva or an adult insect, and in the light of our present knowledge along this line it would perhaps be impossible to ascertain definitely how an ovicide affects insect eggs. For this reason no attempt was made in the present investigation to determine how nicotine sulphate killed the eggs tested. Nevertheless a little theory on this subject may not be out of place here.

Before attempting to explain how nicotine sulphate acts as an ovicide, it is first necessary to know something about the coverings of an insect egg. It is well known, as compiled by Packard (8, p. 520), that a ripe insect egg has two coverings. The external one, the egg-shell or chorion, is usually thick and hard; it is pierced by one or more minute canals, the micropyles, and consists of two chitinous-like laminae kept in close apposition by means of numerous minute pillars. The internal covering, the vitelline membrane, is always thin and delicate. The developing embryo inside the egg is supposed to breathe directly through these coverings as does a chick embryo through the shell of a hen's egg.

According to the results already presented, it was ascertained that freshly laid eggs, sprayed with solutions of nicotine sulphate, were affected more than were older eggs likewise treated. The chorions of these eggs were not as hard as those of the older eggs. This fact alone may explain the difference in the mortality recorded. Since it is scarcely possible that the spray solutions passed through the eggshells, there remain two possible methods of explaining the death of the eggs sprayed: (1) Upon evaporation of the spray solutions there was usually left a thin film on the leaves sprayed, and perhaps also on the eggs. This film on the eggs might have decreased the aeration through the eggshells and thus caused death by suffocation. (2) Since practically all of the aborted embryos appeared to have died during the last stage of development, the preceding view does not seem to have much weight. As the sprayed surfaces continued to emit a nicotine-like odor for some time after the spray solutions had been applied, it seems reasonable to suppose that the embryos were killed by breathing the exhalation from the sprayed surfaces through the eggshells. Nicotine is a nerve poison, and the more highly developed

the nervous system the more effective the poison. This fact probably explains why practically all of the embryos that died succumbed during the last stage of development.

Feytaud (3) described five stages in the embryology of (*Eudemis*) *Polychrosis botrana* Schiff. and of (*Phalonia*) *Conchylis ambiguella* Hbn., and he treated many eggs of these moths with various strengths of pure nicotine and soap. The resulting mortality varied considerably, but even the strongest solution (1:666) used did not prove efficient. He tested the eggs in the various stages of development, but in almost every case in which the embryos died they succumbed during the last stage.

Lovett (4) sprayed apple-tree foliage with solutions of nicotine sulphate, and after several hours, when the leaves were perfectly dry, he placed many small tent caterpillars (*Malacosoma pluralis* Stretch) on these leaves. He states that these caterpillars showed a decided aversion for the sprayed leaves; all of them soon became sick and a large percentage of them died. On the third day after the foliage had been sprayed more caterpillars were placed on the same leaves and similar results were obtained. The leaves were not eaten. Lovett performed other experiments in which the caterpillars slightly ate the leaves which had been sprayed several hours previously. In this case the action of the nicotine was quick and decisive. These results agree with those given in the preceding pages.

Theoretically nicotine sulphate is nonvolatile, although we know from experience that the commercial 40 per cent nicotine sulphate (the kind used in all the preceding experiments) is more or less volatile. Moore and Graham (7) state that pure nicotine sulphate is nonvolatile, and demonstrated that its vapor or exhalation (if either one is given off) did not kill the insects tested. They also state that commercial 40 per cent nicotine sulphate contains from 1 to 2 per cent of free nicotine, whose vapor did kill the insects tested. Moore and Graham claim that when spray solutions are prepared by using commercial nicotine sulphate, hard water, and soap, the nicotine sulphate is decomposed, setting free the nicotine; the amount of decomposition depends upon the amount of alkalies contained in the solutions. This view easily explains the presence of a thin film (already mentioned several times) left upon evaporation of the spray solution, which is certainly the nonvolatile portion of the nicotine sulphate contained in the solution. For some time after the application of the solution the film continues to emit an odor and its exhalation is more or less toxic to young larvæ, showing that it is not pure nicotine sulphate according to Moore and Graham.

Moore and Graham (7) state that 12 days after lettuce in a greenhouse had been sprayed with a solution of commercial 40 per cent nicotine sulphate, it still bore nicotine.

To determine how long nicotine sulphate may remain on fruit-tree foliage after the application of the spray solution, the following experiments were performed by McIndoo. On September 10 a small pear tree was sprayed with a solution of commercial 40 per cent nicotine sulphate 1:800, containing fish-oil soap (2 pounds to 100 gallons water). On various days thereafter about a quart of the sprayed leaves were collected on each recorded date; the leaves, after being ground in a meat grinder, were then mixed thoroughly with water containing sodium carbonate. Upon distilling this mixture a distillate containing nicotine was obtained on each day tested up to the thirty-fifth day after the leaves had been sprayed. On the forty-second day after applying the spray solution only an indication of a precipitate was observed, but concluding from the precipitates obtained prior to this date the amounts of nicotine present in the distillates seemed to decrease irregularly from the first to the forty-second day; soon after which the remaining leaves fell from the trees. During these tests there was comparatively little rainfall; nevertheless the results of the tests indicate that considerable rainfall is required to remove all of the nicotine sulphate adhering to the sprayed leaves. The details of these tests are presented in Table IV:

TABLE IV.—*Tests on various dates using pear-tree leaves which had been sprayed on Sept. 10 with a solution of commercial 40 per cent nicotine sulphate (1:800) containing soap to show the presence of nicotine.*

Date.	Number of days after leaves had been sprayed.	Kind of precipitate obtained using—		Amount of rainfall.	Remarks.
		Phosphomolybdic acid.	Silicotungstic acid.		
Sept. 11	1	Heavy....	Heavy....	<i>Inches.</i> 0.00	Sprayed leaves emit nicotinellike odor.
Sept. 12	2	...do.....	...do.....	.00	Do.
Sept. 12	(1)	None.....	None.....	.00	Unsprayed leaves on another tree were used.
Sept. 13	3	Heavy....	Heavy....	.00	Sprayed leaves do not emit nicotinellike odor.
Sept. 14	4	...do.....	...do.....	.14	
Sept. 15	5	.....	.....	.01	
Sept. 16	6	.....	.....	.08	
Sept. 18	8	Fair.....	Faint....	.00	
Sept. 24	14	...do.....	Very faint.	T.	
Sept. 27	17	.....	.....	.07	
Sept. 28	18	.....	.....	.16	
Oct. 1	21	Fair.....	Very faint.	.00	
Oct. 4	24	.....	.....	.01	
Oct. 5	25	.....	.....	.20	
Oct. 8	28	Fair.....	None.....	.07	
Oct. 9	29	.....	.....	.35	
Oct. 11	31	.....	.....	.01	
Oct. 12	32	.....	.....	.36	
Oct. 15	35	Very faint.	None.....	T.	
Oct. 19	39	.....	.....	.89	
Oct. 20	40	.....	.....	.01	
Oct. 22	42	Indication.	None.....	.....	
Total amount of rainfall during tests...				2.36	

¹ Control.

At the suggestion of Mr. V. I. Safro, McIndoo washed separately 50 sprayed pear-tree leaves in 50 cc. of water. The resulting filtrate was acidified with hydrochloric acid and then tested for the presence of nicotine by adding phosphomolybdic acid and silicotungstic acid. Each test apparently showed the presence of nicotine. Fifty unsprayed leaves were likewise tested as a control; no precipitate was observed. One hundred unsprayed leaves were also tested, using the same amount of water; this time a precipitate was observed, and the same result was obtained thereafter on several occasions. Only green and unbroken leaves were used in these tests. At all times there is more or less foreign organic matter in the form of dust on the leaves; this is readily seen in microscopical sections through unsprayed leaves, and alkaloidal reagents precipitate it, as well as the nicotine which may be present. Consequently the preceding method should not be regarded as reliable; nevertheless, Mr. Safro (9) has published his method and says:

Generally we are able to obtain a definite indication of the presence of nicotine in as little as 25 cc. of water by using five leaves that had been sprayed at the usual strength (about 0.05 of 1 per cent nicotine).

On the fourth day after the pear tree used in the experiments had been sprayed, about a quart of the sprayed leaves were collected and washed in water containing sodium carbonate, each leaf being washed separately. Next the leaves were washed in running water for 5 minutes, and were finally ground and tested as described above. By adding phosphomolybdic acid to the resulting distillate, a faint precipitate was obtained, but none by adding silicotungstic acid. On the eighth day after the leaves had been sprayed, the test was repeated, but this time the leaves were washed for 10 minutes in running water. No precipitate was observed in this test even by adding phosphomolybdic acid. In each of the two foregoing tests the water containing the sodium carbonate and foreign matter removed from the leaves was distilled. Adding either acid to the resulting distillate invariably produced a precipitate, but in none of the tests with sprayed leaves did the distillate ever emit a nicotine odor. The second experiment described above indicates either that the spray solution did not pass into the leaves or that the amount of nicotine still held by them was too small to be detected by the method employed. The following results will substantiate the former view:

A small quantity of nicotine-sulphate solution (1:800) containing fish-oil soap (2 pounds to 100 gallons of water) was colored with carmine acid (Grübler's Carminsaur) and an equal quantity with indigo carmine (sodium sulphindigotate). Several leaves on a pear tree were sprayed with each of the colored solutions, and two entire detached leaves were submerged in each solution for 15 minutes; the

petioles of the leaves were left projecting above the surfaces of the solution. An hour later the four treated leaves were put into absolute alcohol and a day later a few of the stained leaves on the tree were likewise treated. The absolute alcohol did not dissolve or scatter either one of the stains, and the only other reagents used were xylol and Canada balsam; these also did not scatter the stains. A study of the sections made shows much stain on the outside of the sprayed and submerged leaves. While none was observed inside the sprayed leaves, it was usually present inside the submerged ones and the most of it seems to have passed through the ventral surfaces of the leaves. Its passage may have been aided by the stomata which occur exclusively on the ventral surface of these leaves; botanists, however, say that the stomata are so small (0.0006 mm. and less) that neither dust nor water can pass through them into the plant. According to the above results the spray solutions did not pass into the leaves sprayed, nor did the dust in the film of adhering nicotine sulphate enter the stomata.

SUMMARY OF EXPERIMENTS CONDUCTED IN LABORATORY.

Nicotine sulphate as an ovicide, with one exception, was found inefficient against all of the eggs tested—namely, those of the silkworm moth, codling moth, tussock moth, and potato beetle. The eggs sprayed with it were variously affected, depending on the strength of the spray solution used, on the age of the eggs tested, and whether or not the solution contained soap. Upon the eggs of three of the species of insects used there was practically no difference in effects between solutions containing soap and those without soap, although those with soap were much more effective upon the eggs of the tussock moth. Comparing the effects of the spray solution 1:800, the strongest one of the economic solutions used, the percentages of eggs sprayed with it that failed to hatch are as follows: Ninety-nine per cent of the freshly laid eggs of the silkworm moth, but only about 75 per cent of the older eggs of the same insect; about 20 per cent of the codling-moth eggs on apple-tree foliage; 75 per cent of the tussock-moth eggs (1 to 3 days old); and about 12 per cent of those of the same insect which had been collected in the field; and practically none of the potato-beetle eggs.

The effects of the exhalation from leaves sprayed with solutions of nicotine sulphate varied considerably, depending on the larvæ tested and the strength of the solutions used. Again comparing the effects of the solution 1:800, all of the newly hatched silkworms and codling-moth larvæ placed upon leaves sprayed two hours previously died, but the silkworms succumbed the more quickly; all of the silkworms but only a small percentage of the codling-moth larvæ placed upon leaves sprayed 24 hours previously died.

Seventy-seven per cent of the newly hatched codling-moth larvæ placed upon pears sprayed 24 hours previously with a solution of nicotine sulphate 1:800 died, but only 33 per cent of those placed upon pears sprayed a week previously died.

Relative to the control of the codling moth, the following briefly summarizes the more important points herein recorded: About 20 per cent of the freshly laid eggs sprayed with a solution of nicotine sulphate 1:800 failed to hatch, and one-third of the remaining embryos that emerged died before they entered pears sprayed a week previously. Hence about one-half of the eggs and larvæ had been destroyed up to the time when the remaining larvæ entered the sprayed pears; a large percentage of the latter larvæ died, as about 60 per cent of the pears did not become wormy. According to these laboratory results nicotine sulphate does not seem to be efficient against the codling moth, although only one application of it was made; nevertheless its effectiveness would certainly be increased in proportion to the number of its applications and to the amount of rainfall.

EXPERIMENTS CONDUCTED IN ORCHARDS.

According to the preceding laboratory results nicotine sulphate would not seem to be efficient against the codling moth. To determine this from the practical viewpoint the following experiments were conducted:

EXPERIMENTS PERFORMED AT BENTON HARBOR, MICH.

The experimental work conducted at Benton Harbor consisted in testing the relative efficiency of nicotine sulphate when combined with soap and when combined with soap and arsenate of lead in contrast with the efficiency of arsenate of lead when combined with lime-sulphur at summer strength. The experiments were made in a sod orchard about 50 years old, and each of the four plats selected consisted of 16 trees.

All of the applications throughout the season were made with the same power sprayer and at a pressure well above 100 pounds. The spray was delivered through the Vermorel type of nozzle. Although the experiments were started with the calyx application, all of the plats, including the check (No. 4), were given the cluster bud application.

The set of fruit was scattered and rather light, being lightest in plat No. 3, but it was sufficient to give reliable experimental results. In order that trees with as uniform a crop as possible might be secured throughout the different plats, five count trees in each plat were not selected until after the fruit had set. The fallen fruit was

collected once a week and examined for codling-moth injury, and at picking time the picked fruit was also examined. The results of these examinations are given in Table V.

TABLE V.—*Codling moth injury as shown by examination of both fallen and picked fruit from experimental plats at Benton Harbor, Mich., 1917.*

No. of plat.	Number of applications and brief formula of each.	Fruit record.					
		Number of larval entrances at—			Number of wormy apples.	Total number of apples examined.	Percentage of total number of apples free from worms.
		Calyx.	Side.	Stem.			
1	1 application of lime-sulphur and 3 applications of lime-sulphur + 1 pound arsenate of lead to 50 gallons water.....	191	277	14	336	6,543	94.71
2	1 application of lime-sulphur and 3 applications of nicotine sulphate 1:800+soap.....	559	652	71	1,249	9,924	87.41
3	1 application of lime-sulphur and 3 applications of nicotine sulphate 1:800+soap+0.5 pound of arsenate of lead to 50 gallons of water.....	40	195	4	231	2,949	92.15
4	1 application of lime-sulphur (check)...	2,032	607	93	2,484	6,060	59.00

Reference to Table V shows that nicotine sulphate (plat No. 2) gave a control of only 87.41 per cent, while arsenate of lead (plat No. 1) gave a control of 94.71 per cent. There is thus seen to be no practical advantage in combining arsenate of lead with nicotine sulphate in sprays designed to control the codling moth (plats Nos. 1 and 3).

EXPERIMENTS PERFORMED AT GRAND JUNCTION, COLO.

Experiments similar to the preceding were also performed at Grand Junction, Colo. Of the 12 plats sprayed, only 2 were sprayed with nicotine sulphate, but since the results obtained using arsenate of lead vary so greatly, the data from 4 of the latter plats are given in Table VI, so that the results from the plat sprayed with nicotine sulphate may be compared with those from the plats sprayed with arsenate of lead alone and also with the results from the plat sprayed with arsenate of lead and nicotine sulphate combined. In plats on which it was applied (i. e., all except plats Nos. 10, 14, and 15), the calyx application was made with a Bordeaux type of nozzle which delivered a fairly coarse and driving spray; a mist type of nozzle was used for all subsequent applications. With this exception the same spraying equipment was used for all plats except the checks.

At various times throughout the growing season and at harvest time the apples on eight trees in each plat (four in each of the two check plats) were examined; the results of these examinations, together with the treatment of the several plats, are given in Table VI.

TABLE VI.—*Codling-moth injury as shown by examination of both fallen and picked fruit from experimental plats at Grand Junction, Colo., 1917.*

Plat No.	Formula of insecticide.	Number of applications.			Total number of apples examined.	Fallen apples free from worms.	Harvested apples free from worms.	Total apples free from worms.
		For first brood.	For second brood.	Total.				
						<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
2	1 pound of powdered arsenate of lead to 50 gallons of water.....	4	2	6	23,508	37.75	72.16	62.09
3	Nicotine sulphate (1:800).....	4	2	6	29,881	17.32	58.33	37.96
4	1 pound of powdered arsenate of lead to 50 gallons of water plus nicotine sulphate (1:800).....	4	2	6	24,003	40.97	84.17	67.50
8	1 pound of powdered arsenate of lead to 50 gallons of water.....	3	2	5	38,874	48.28	82.31	73.49
9	Same as above.....	4	3	7	47,773	47.74	85.53	76.53
10	Same as above.....	1	3	5	37,628	22.83	60.69	46.33
14 and 15	Check (unsprayed).....				33,882	7.36	15.01	8.72

¹ All three were cover applications, the calyx application being omitted.

Although the results in the preceding table vary considerably, it is seen nevertheless that nicotine sulphate when used alone was inefficient (plat No. 3).

EXPERIMENTS PERFORMED AT ROSWELL, N. MEX.

The experimental work conducted at Roswell consisted in a comparison of the efficiency of nicotine sulphate with that of arsenate of lead alone and also with that of arsenate of lead combined with nicotine sulphate. For this purpose four plats, lying in a 640-acre tract of apple trees, were selected; they were similar in all respects and the trees, about 20 years old, were of the Ben Davis variety. Following the regular 5-spray schedule, all the plats, except the check (No. 4), were sprayed on the following dates: April 25, May 15, June 14, July 18, and August 14. During the first application about 21 gallons of spray material were applied to each tree, but during each subsequent application only about 17 gallons per tree were used. Bordeaux nozzles were used for the calyx application and a mist type for the other applications. A power sprayer, holding 200 gallons, was employed, and the pressure was maintained at 200 pounds with three leads of hose.

During these experiments the dates and amounts of rainfall are as follows: May 6, 0.23 inch; July 19, 0.03 inch; July 20, 0.03 inch; August 1, 0.54 inch; August 2, 0.47 inch; August 15, 0.15 inch; August 17, 0.60 inch; and August 18, 0.93 inch, giving a total of 2.98 inches.

The details pertaining to the plats, formulas of application, and results of the foregoing experiments are given in Table VII.

TABLE VII.—*Codling-moth injury as shown by examination of both fallen and picked fruit from experimental plats at Roswell, N. Mex., 1917.*

Plat No.	Number of applications and formula of each.	Fruit record.			
		Total number of apples examined.	Fallen apples free from worms.	Harvested apples free from worms.	Total apples free from worms.
1	5 applications of 1 pound of powdered arsenate of lead to 50 gallons of water.....	1 33,472	Per cent. 93.64	Per cent. 97.66	Per cent. 96.88
2	5 applications of 1 pound of powdered arsenate of lead to 50 gallons of water+nicotine sulphate (1:800)+ $\frac{3}{4}$ pound of laundry soap.....				
3	5 applications of nicotine sulphate (1:800)+ $\frac{3}{4}$ pound of laundry soap to 50 gallons of water.....	2 7,011	85.55	98.99	97.00
4	Unsprayed.....	3 6,170	88.01	93.43	91.94
		4 14,401	52.06	50.01	51.53
1 On 6 trees.		2 On 4 trees.		3 On 4 trees.	
				4 On 12 trees.	

From Table VII it is seen that the trees sprayed with nicotine sulphate (plat No. 3) yielded a crop of apples 92 per cent sound, while those sprayed with arsenate of lead (plats Nos. 1 and 2) yielded a crop 97 per cent sound, and that the addition of nicotine sulphate to the arsenate of lead mixture (plat No. 2) did not materially increase the percentage of sound fruit.

CONCLUSIONS FROM FIELD EXPERIMENTS.

According to the work conducted during the season of 1917, it is shown that nicotine sulphate 1:800 with soap gave a fair degree of control for the codling moth at Benton Harbor, Mich., and at Roswell, N. Mex., but that it was not as effective as 1 pound of powdered arsenate of lead to 50 gallons of water; and also that there was no practical advantage in combining arsenate of lead and nicotine sulphate in sprays designed to control the codling moth. Of course it is well known that nicotine sulphate controls aphids on fruit trees, but this phase of the subject is not considered in this paper. At Grand Junction, Colo., where the infestation was much heavier, nicotine sulphate 1:800 without soap was inefficient against the codling moth.

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PROFESSIONAL PAPER

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EXPERIMENTS AND SUGGESTIONS FOR THE CONTROL OF THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.¹

By E. H. SIEGLER, *Entomologist*, and H. K. PLANK,² *Scientific Assistant, Fruit Insect Investigations, in cooperation with the Colorado Agricultural Experiment Station.*

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Owing to the great abundance and destructiveness of the codling moth (*Laspeyresia pomonella* L.) in the Grand Valley of Colorado, the Bureau of Entomology of the United States Department of Agriculture, in cooperation with the Colorado Agricultural Experiment Station, undertook in 1915 a study of its life history and control. The biological study was concluded the following year, but the control investigations continued during 1916, 1917, and 1918.

In this report are given the more important results of the spraying experiments and some suggestions for the control of the codling moth in the Grand Valley.

¹ In 1915 and 1916 the senior author was in immediate charge, assisted by E. R. Van Leeuwen, of the Bureau of Entomology, during the former season and by H. K. Plank, also of the bureau, during the latter. In 1917 Mr. Plank had charge of the project, assisted by Leo. C. Antles, of the Colorado Agricultural Experiment Station, and during the following year Mr. Antles carried out the experiments under the general direction of Mr. Plank and the Colorado Experiment Station.

Dr. A. L. Quaintance, in charge of fruit insect investigations, Bureau of Entomology, and Dr. C. P. Gillette, George M. List, and Claude Wakeland, of the Colorado Agricultural Experiment Station, made many helpful suggestions throughout the course of the work. The writers also wish to express their appreciation for the cooperation of the Grand Valley fruit growers.

² Resigned June 30, 1920.

THE GRAND VALLEY OF COLORADO.

The Grand Valley is one of the most important fruit-growing regions of Colorado, having approximately 15,000 acres devoted to such fruits as apples, pears, peaches, plums, cherries, and bush fruits. About 10,000 of these acres are planted to apples and 2,500 to pears, both of which (and particularly the apple) are heavily attacked by the codling moth.

LOCATION AND TOPOGRAPHY.

The Grand Valley is in the western part of Mesa County and extends from Palisades to Fruita, about 32 miles. The valley follows the course of the Grand River and is generally level, except for the sections known as the Fruit Ridges, which are somewhat elevated and rolling. The district of Orchard Mesa, although higher than the rest of the valley, is typical level, or mesa, land. The lower part of the valley is approximately 4,500 feet above sea level and the upper district at Palisades is about 4,800 feet in elevation.

CLIMATE.

The climate is comparatively dry, and the crops are irrigated principally by means of water taken from the Grand River. The annual precipitation is but 8 to 9 inches, and during the five months from May to September, in which season the apple and codling moth are developing, the rainfall amounts to only from 3 to 4 inches. The mean normal temperature during the same period is about 70.6° F.

COMPARISON OF THE CLIMATIC CONDITIONS OF GRAND JUNCTION, COLO., AND ROCHESTER, N. Y.³

Since the development and severity of the codling moth are largely influenced by climatic factors, it may be of interest to compare the weather conditions of the Grand Valley with those of the western New York apple belt. Under the semiarid conditions that exist in the Grand Valley, the codling moth causes great injury to the fruit crop and is very difficult to control, whereas under the relatively cooler and more humid conditions of western New York the codling moth is much less troublesome.

In Table 1 will be found data giving a comparison of the mean normal temperature and precipitation of Grand Junction, Colo., and Rochester, N. Y.⁴ It will be noted therein that the total normal precipitation in the Grand Valley during the growing season, or from May to September, inclusive, is only about one-fourth as much as in western New York and that the mean temperature is about 6° F. higher than that of Rochester, N. Y.

³ Grand Junction, Colo., is the approximate center of the Grand Valley, and Rochester, N. Y., is in the midst of the western New York apple belt.

⁴ Climatological data, U. S. Weather Bureau.

TABLE 1.—Comparison of mean normal temperature and precipitation, Grand Junction, Colo., and Rochester, N. Y.

Month.	Grand Junction, Colo.		Rochester, N. Y.	
	Mean normal temper- ature.	Mean normal precipi- tation.	Mean normal temper- ature.	Mean normal precipi- tation.
	° F.	Inches.	° F.	Inches.
May.....	58.9	0.92	55.7	2.94
June.....	72.6	0.40	65.9	3.13
July.....	79.2	0.50	70.4	3.09
August.....	76.1	1.04	68.3	2.96
September.....	66.4	0.95	61.9	2.32
Average or total.....	70.6	3.81	64.4	14.44

In the course of the life-history investigations in the Grand Valley it was found that a female moth deposited as many as 316 eggs and that several laid over 300 eggs each.⁵ In other localities where the Bureau of Entomology has conducted similar investigations, the fecundity of the female moth has never been found to be so high. The nearest approach to the individual egg production in the Grand Valley was found in the Pecos Valley of New Mexico, where like climatic conditions obtain and where one female moth was recorded to have produced 259 eggs.⁶ In the fruit belt of western Michigan, where the weather conditions approximate those of western New York, the most eggs laid by a moth, according to the records of A. G. Hammar, was 161.⁷

It has been quite generally established that semiarid climatic conditions are very favorable to the development of the codling moth, whereas humid conditions and lower temperatures retard its development.

SPRAYING EXPERIMENTS IN THE GRAND VALLEY.

Spraying experiments were conducted in several orchards during the seasons of 1915, 1916, 1917, and 1918, on representative apple varieties. The results herewith presented, however, are confined to the Ben Davis and Gano, since the Grand Valley fruit growers generally experienced more difficulty in controlling the codling moth on these than on any other commercial varieties.

In the spraying experiments described an attempt was made to time the spray applications according to the development of the codling moth as indicated by the life-history studies and field obser-

⁵ Siegler, E. H., and Plank, H. K. The Life History of the Codling Moth in the Grand Valley of Colorado. U. S. Dept. Agr. Bul. 932. 1921.

⁶ Quaintance, A. L., and Geyer, E. W. Life History of the Codling Moth in the Pecos Valley, New Mexico. U. S. Dept. Agr. Bul. 429. 1917.

⁷ Hammar, A. G. Life History Studies on the Codling Moth in Michigan. U. S. Dept. Agr. Bur. Ent. Bul. 115, Pt. 1. 1912.

vations. These studies revealed the fact that there are two full broods of larvæ and a partial third during the growing season in the Grand Valley and that these overlap to a certain extent, some larvæ hatching practically every day. In general, the hatching of each brood of larvæ begins first in small numbers, then in increasing numbers until the maximum is attained, after which there is a gradual decrease until the last larva of the brood has hatched.⁸ A tentative spraying schedule, based on certain intervals between applications, was adopted and closely adhered to throughout the work, except when it seemed advisable or became necessary to deviate therefrom.

SPRAYING EXPERIMENTS IN 1915.

The growing season of 1915 was extremely abnormal in so far as it related to the crop of apples and abundance of the codling moth. The fruit crop of the valley was practically destroyed just as the petals had dropped by the freezes of May 2, 3, and 4. Temperatures as low as 22° F. were recorded in some sections, killing apples and pears except at Palisades where peaches constitute the chief crop and in a few smudged orchards located elsewhere.

The apple orchard of Mr. Gus J. Johnson, of Highland Park, was among those that were partly saved by the timely use of oil heaters, and was available for experimental purposes. (Pl. I, fig. 1.) This orchard consisted of the Ben Davis, Jonathan, Black Twig, Winesap, and Rome Beauty varieties and was divided into 10 plats, including the unsprayed or check plat.

In Tables 2 and 3 will be found data of the experiments. Two spray poles were used, one of which was operated from the top of the spray tank and the other from the ground. Bordeaux nozzles were used for the calyx treatment except in Plat VI, and nozzles of the eddy-chamber or whirlpool-disk type were employed for all cover sprays in all of the sprayed plats except in plat VI; in this plat Vermorel nozzles were used in all applications. Plats I, II, and IX, located in different sections of the orchard, received identical treatment, a total of four cover sprays, two for the first brood and two for the second and third broods. Plats III and IV were given five cover sprays each, the former receiving three for the first brood and two for the later broods and the latter two for the first and three for the subsequent broods. Plat V was given a total of three cover sprays, two for the first brood and one for the broods that followed. Plat VI was sprayed throughout the season with a very fine mist spray delivered by Vermorel nozzles under a pressure of 90 pounds. Two cover sprays were applied for the first-brood larvæ followed by two more cover sprays for the second and third broods, making four cover treatments in all. Plats VII and VIII were given the same number of applica-

⁸ For further details see U. S. Dept. Agr. Bul. 932, *The Life History of the Codling Moth in the Grand Valley of Colorado*, by the present authors.

tions as plats I, II, VI, and IX, but in plat VII homemade arsenate of lime paste⁹ was substituted for arsenate of lead paste, and in plat VIII commercial arsenate of lime powder was used. Plat X was unsprayed for comparison with the treated plats.

TABLE 2.—*Spraying schedule for the codling moth, Johnson orchard, Grand Valley of Colorado, 1915.*

Number of plat.	Calyx spray.	Cover sprays—first brood.			Cover sprays—second and third broods.		
	A. °	B.	C.	D.	E.	F.	G.
	Petals off, May 5-7.	3 to 4 weeks after A, May 24-26.	21 to 22 days after B, June 14-15.	14 days after C, June 28.	10 to 11 weeks after A, July 16-17.	21 to 24 days after E, Aug. 6-9.	22 days after F, Aug. 28.
I.....	First.....	Second....	Third.....		Fourth....	Fifth.....	Sixth.
II.....	do.....	do.....	do.....		do.....	do.....	
III.....	do.....	do.....	do.....	Fourth....	Fifth.....	Sixth.....	
IV.....	do.....	do.....	do.....		Fourth....	Fifth.....	
V.....	do.....	do.....	do.....		do.....		
VI.....	do.....	do.....	do.....		do.....	Fifth.....	
VII.....	do.....	do.....	do.....		do.....	do.....	
VIII.....	do.....	do.....	do.....		do.....	do.....	
IX.....	do.....	do.....	do.....		do.....	do.....	
X.....	Check.....					do.....	

TABLE 3.—*Treatment of plats for the codling moth, Johnson orchard, Grand Valley of Colorado, 1915.*

Number of plat.	Spray materials.	Pressure.	Spraying equipment.	
			Calyx spray.	Cover sprays.
I.....	Arsenate of lead, paste, 2 pounds—50...	<i>Pounds.</i> 200-225	Bordeaux nozzles.	Whirlpool-disk nozzles.
II.....	do.....	200-225	do.....	Do.
III.....	do.....	200-225	do.....	Do.
IV.....	do.....	200-225	do.....	Do.
V.....	do.....	200-225	do.....	Do.
VI.....	do.....	90	Vermorel nozzles.	Vermorel nozzles.
VII.....	Arsenate of lime, homemade, 2 pounds—50.	200-225	Bordeaux nozzles.	Whirlpool-disk nozzles.
VIII.....	Arsenate of lime, commercial powder, $\frac{1}{2}$ pound—50.	200-225	do.....	Do.
IX.....	Arsenate of lead, paste, 2 pounds—50..	200-225	do.....	Do.
X.....	Check—unsprayed.....	.....	.....	.....

The results of these experiments will be found in Table 4, by reference to which it will be seen that plats I, II, and IX, the treatments of which were alike, produced from 52.88 to 68.41 per cent of fruit free from worms. Under the varying conditions that exist in most orchards, such as unevenness of insect infestation, likelihood of moth migration, differences among the trees in the crop yield, and other contributing factors, uniform results can not always be obtained. Because of these conditions in commercial orchards one section frequently is wormier than another, although the treatment is uniform

⁹ For method of preparation see U. S. Dept. Agr. Bul. 278, Miscellaneous Insecticide Investigations, by E. W. Scott and E. H. Siegler.

throughout the orchard. Plat III, in which three cover applications were made for the first brood and two for the later broods, produced the best crop of apples from the point of insect control, 72.22 per cent of the fruit being free from worms. Plat IV was treated with the same number of cover sprays as plat III, but the number of applications for the broods was reversed, and with this treatment 66.48 per cent of the fruit was free from worm infestation. In plat V only three cover sprays were applied, and the treatment resulted in 62.21 per cent of uninfested fruit. As previously noted, plat VI was sprayed five times by means of Vermorel nozzles with a pressure of but 90 pounds, producing a very fine mistlike spray. Generally speaking the results indicate that this treatment was as effective as the other methods employed, there being 63.78 per cent of worm-free fruit. The low-pressure mist spray also gave as good results as the high-pressure coarse sprays in preventing the entrance of larvæ through the calyx end of the apple. It should be borne in mind, however, that in commercial spraying a reasonably high pressure of 200 to 250 pounds will increase the speed of the work and that the distribution of the spray material is likely to be more thorough than when applied under a low pressure.

Arsenate of lime, both homemade and commercial, as used in plats VII and VIII, gave comparatively poor results.

The unsprayed or check trees, plat X, were very wormy, giving but 13.51 per cent of fruit free from larvæ.

The sprayed fruit was well protected against the calyx entrance worms except in plat VIII. With this exception, the percentage of wormy apples infested at the calyx in the sprayed plats varied from 3.72 to 5.92. The unsprayed plat produced 55.06 per cent of wormy fruit infested at the calyx.

TABLE 4. *Summary of results of spraying for the codling moth, Johnson orchard, Grand Valley of Colorado, 1915*

Plat.	Number of trees examined.	Total number of apples examined.	Total number of worms (including extra).	Average number of worms for all apples.	Average number of worms for wormy apples.	Per cent of worms (including extra) entering apples.			Per cent of wormy apples infested.			Total number of stings.	Average number of stings for all apples.	Per cent of worm-free apples free from stings.	Per cent of all apples free from worms
						At calyx.	At side.	At stem.	At calyx.	At side.	At stem.				
I.	8	12	0	0	1.36	0	0	0.24	0	0	0.38	1	1.26	100	55.06
II.	12	20	4	0.20	1.36	2	2	1.34	2	2	1.34	5	0.25	40	34.44
III.	12	20	12	0.60	1.36	2	2	1.34	2	2	1.34	17	0.85	22	22.22
IV.	12	20	17	0.85	1.36	2	2	1.34	2	2	1.34	17	0.85	22	22.22
V.	12	20	11	0.55	1.36	2	2	1.34	2	2	1.34	11	0.55	45	34.44
VI.	12	20	12	0.60	1.36	2	2	1.34	2	2	1.34	12	0.60	40	34.44
VII.	12	20	12	0.60	1.36	2	2	1.34	2	2	1.34	12	0.60	40	34.44
VIII.	12	20	12	0.60	1.36	2	2	1.34	2	2	1.34	12	0.60	40	34.44
IX.	12	20	12	0.60	1.36	2	2	1.34	2	2	1.34	12	0.60	40	34.44
X.	12	20	12	0.60	1.36	2	2	1.34	2	2	1.34	12	0.60	40	34.44

In the treated plats over 90 per cent of the worms actually infesting the fruit gained entrance through the side of the apple and less than 7 per cent entered by way of the calyx. In untreated plat X 72.31 per cent of the larvæ entered through the side of the fruit and 26.45 per cent through the calyx end. It will thus be seen from these data that one of the chief difficulties in controlling the codling moth in the Grand Valley of Colorado is to prevent the larvæ from entering the apple through the side.

In the plats where arsenate of lead was employed the average number of larvæ for worm-infested fruit varied from 1.39 to 1.67, whereas in the arsenate of lime plats this average was increased to 1.86 and 2, and in the unsprayed plat there was a further increase to 2.08 larvæ for each wormy apple. The higher the percentage of apples free from worms the lower the average number of worms per apple. Thus in plat III, where the best control was obtained and where 72.22 per cent of apples were free from worms, there was an average of only 0.39 larva per apple, and in plat X, which was unsprayed and yielded but 13.51 per cent of worm-free fruit, there were 1.80 larvæ per apple.

In scoring results, account was taken of the so-called codling moth "sting" (Pl. II). The sting is a shallow excavation extending through the skin of the apple into the flesh to a depth of about one-sixteenth to three thirty-seconds of an inch. It is caused by newly hatched larvæ that only succeed in eating their way through the skin before succumbing to the poison, or, for other reasons, do not penetrate deeper into the fruit. In the sprayed plats the average number of stings per apple varied from 0.82 to 1.91, whereas in the unsprayed plat the average was only 0.12.

It is the belief of the writers that, with a uniform infestation and crop and with other factors equal, the number of stings is directly proportional to the number of worm-free apples. In other words, if the spray treatment is effective, the only indication of worm attack will be found in the sting marks, and these will increase within certain limits as the number of worm-free apples increases. In the case of unsprayed fruit, the worms are not subjected to a poison, and hence what might result in only a sting in a sprayed apple becomes a worm hole in the untreated fruit. It should not be inferred, however, that unsprayed fruit is totally devoid of stings, for sting marks sometimes occur on untreated fruit and may be accounted for by larvæ which start an entrance hole and then change to another place, or by larvæ that, before penetrating very far into the fruit, are blown off by wind, brushed off by foliage, or washed off by heavy rains.

SPRAYING EXPERIMENTS IN 1916.

In 1916 the Gus J. Johnson orchard, at Highland Park, and the J. D. Nettleton orchard, at Fruitvale, were used for experimental purposes.

In the Johnson orchard the principal part of the experimental work was a test of the efficiency of coarse sprays applied with a short rod and Bordeaux nozzle in comparison with mist sprays applied by means of spray poles equipped with whirlpool-disk nozzles.

The short rod referred to consisted of a piece of iron pipe about 1 foot in length, to one end of which was attached a Bordeaux nozzle and to the other a cut-off to which the hose was connected. Under a pressure of 225 to 250 pounds and with the nozzle sufficiently open, the spray was practically a solid stream as it left the nozzle, but broke up more or less as it reached the tree. This type of spraying apparatus had been used by many Grand Valley growers for several seasons in preference to the spray poles, formerly employed, because it rendered spraying less burdensome and increased the speed of the work. The spray gun, which was subsequently developed, is an improvement over the short rod, in that the character of the spray can be readily graduated from fine to coarse.

The spray history of the experiments in the Johnson orchard will be found in Tables 5 and 6.

TABLE 5.—*Spraying schedule for the codling moth, Johnson orchard, Grand Valley of Colorado, 1916.*

Number of plat.	Calyx spray.	Cover sprays—first brood.				Cover sprays—second and third broods.	
	A.	B.	C.	D.	E.	F.	G.
	Petals off, May 2-3.	3 to 4 weeks after A, May 29.	14 days after B, June 12.	18 days after B, June 16.	14 days after C, June 26.	9 to 10 weeks after A, July 8.	34 to 41 days after F, Aug. 11-18.
I.....	First.....	Second.....	Third.....		Fourth.....	Fifth.....	Sixth.....
II.....	do.....	do.....	do.....		do.....	do.....	Do.....
III.....	do.....	do.....		Third.....	do.....	Fourth.....	Fifth.....
IV.....	do.....	do.....		do.....		do.....	Do.....
V.....	do.....	do.....				Third.....	Fourth.....
VI.....	do.....	do.....				do.....	Do.....
VII.....	Check.....						

TABLE 6.—*Treatment of plats for the codling moth, Johnson orchard, Grand Valley of Colorado, 1916.*

Number of plat.	Spraying materials.	Spraying equipment.	
		Calyx spray.	Cover sprays.
I.....	Arsenate of lead, powder, 1 pound—50.	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
II.....	do.....	Short rod and Bordeaux nozzle.	Short rod and Bordeaux nozzle.
III.....	do.....	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
IV.....	do.....	Short rod and Bordeaux nozzle.	Short rod and Bordeaux nozzle.
V.....	do.....	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
VI.....	do.....	Short rod and Bordeaux nozzle.	Short rod and Bordeaux nozzle.
VII.....	Check—unsprayed.....		



FIG. 1.—THE JOHNSON EXPERIMENTAL ORCHARD.



FIG. 2.—APPLE INFESTED BY THE CODLING MOTH, THE YOUNG LARVA
HAVING ENTERED FROM THE SIDE.

CONTROL OF THE CODLING MOTH IN THE GRAND VALLEY
OF COLORADO.



FIG. 1.—CODLING MOTH "STING" ON SIDE OF APPLE.
NATURAL SIZE.



FIG. 2.—VERTICAL SECTION THROUGH A CODLING MOTH "STING."
ENLARGED.

CONTROL OF THE CODLING MOTH IN THE GRAND
VALLEY OF COLORADO.

By reference to Table 7 it will be noted that in each instance the coarse sprays, as applied with the short rod and Bordeaux nozzle, gave control inferior to that on the plats treated with the poles and whirlpool-disk nozzles. Thus, plat I, fine spray, yielded 89.48 per cent of fruit free from worms in comparison with 79.54 per cent in plat II, which was treated with the coarse spray. In plat III, sprayed with the disk nozzles, there was 85.05 per cent of uninfested fruit, whereas in plat IV, treated by means of the Bordeaux nozzle, there was but 71.06 per cent of fruit free from worms. Again, in plat V, which was treated with the fine spray, there was 89.70 per cent of worm-free fruit in comparison with 81.43 per cent in plat VI, which was sprayed with the Bordeaux nozzle. The untreated plat, plat VII, produced 30.98 per cent of fruit free from worms.

It is the belief of the writers that the coarse sprays do not adhere so readily to the fruit, especially to the waxy skin of apples of the Ben Davis type, as do the fine mist sprays. It is believed further that the distribution of the poison is more thorough with the spray poles and disk nozzles than with the short rod and Bordeaux nozzle.

The results of this experiment considered as a whole seem to show that three cover sprays were more efficient than five. But this anomaly may perhaps be accounted for by the fact that there was no fruit in plats V and VI the preceding year, it having been destroyed by the spring freezes; hence, there being no overwintering larvæ on these trees, the infestation came solely from moths that migrated from other trees.

A further study of Table 7 will show, as in the experiments of 1915 (Table 4), that the average number of worms per apple was lowest where the best control was obtained, with a range in this respect among the sprayed plats of from 0.14 to 0.40. In the unsprayed plat there was an average of 1.43 worms per apple. The spray material readily checked the worms from gaining entrance through the calyx, over 90 per cent of the larvæ having entered the fruit through the side. In the sprayed plats from 2 to 9.99 per cent of the wormy fruit was infested at the calyx while in the unsprayed plat 28.43 per cent of the wormy fruit was caused by larvæ that entered by way of the calyx.

The average number of stings in the sprayed plats for all apples varied from 0.34 to 0.82 and in the unsprayed plat the average number was 0.23.

TABLE 7.—*Summary of results of spraying for the codling moth, Johnson orchard, Grand Valley of Colorado, 1916.*

Plat.	Num- ber of trees ex- amined.	Total num- ber of apples ex- amined.	Total num- ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Per cent of worms (in- cluding extra) enter- ing apples.			Per cent of wormy apples infested.			Total num- ber of stings.	Aver- age num- ber of stings for all apples.	Per cent of wormy apples free from sting apples.	Per cent of worm- free apples free from stings.	Per cent of all apples free from worms and stings.	Per cent of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.						
I.....	10	12,156	1,705	0.14	3.16	95.85	0.99	4.22	94.61	1.17	6,384	0.53	57.78	70.82	89.48	63.35
II.....	5	6,066	1,601	.26	7.74	91.07	1.19	9.99	88.56	1.45	3,572	.59	63.42	68.60	79.54	62.18
III.....	10	12,196	2,386	.20	1.60	97.53	.88	2.08	96.76	1.46	6,873	.66	56.56	68.70	85.05	58.43
IV.....	5	4,253	1,693	.40	2.60	96.69	.71	3.57	95.45	.98	5,439	.82	56.16	57.74	71.06	41.03
V.....	10	16,014	2,209	.14	1.49	97.74	.77	2.00	97.03	.97	5,439	.34	63.13	79.07	89.70	70.93
VI.....	5	3,700	898	.23	2.23	97.21	.56	2.91	96.36	.73	1,929	.52	63.90	68.27	81.43	55.59
VII.....	4	3,954	5,669	1.43	13.69	86.52	.79	28.43	70.87	.70	905	.23	78.78	91.10	30.98	28.22

A series of experiments was conducted in the Nettleton orchard, but the results were largely vitiated by frosts during May shortly after the setting of the fruit. As a consequence of the low temperatures, small frost pits or cracks in the epidermis developed in much of the fruit, particularly around the calyx end of the apple. It was practically impossible to force the spray material into these pits which thus served as an ideal place of entrance for the worms. Since the frosted fruit was unevenly distributed in the several plats, there was no fair basis on which to draw a comparison of the value of the different treatments.

SPRAYING EXPERIMENTS IN 1917.

The major part of the experimental spray work during the season of 1917 was done in the orchard of the George Smith estate, at Orchard Mesa. This orchard consisted of approximately 20 acres of Ben Davis apple trees about 20 years of age and of fairly uniform size and vigor. The orchard was divided into 17 blocks, or plats, all of which were treated, except the two check plats XVI and XVII, located in diagonally opposite corners of the orchard. The treatment of the several plats and the schedule of applications are presented in Tables 8 and 9.

A power sprayer delivering about 225 pounds pressure was employed in all of the liquid-sprayed plats, and a power dusting machine was used in the three dust-treated plats. With the exception of plats XIV and XV, which were sprayed by the owner, all of the plats were cared for by the experimental force. In the first or calyx treatment the sprayed plats were sprayed by means of two spray poles, equipped with Bordeaux nozzles, one of which was operated from the spray tower and the other from the ground. In applying the cover sprays, the Bordeaux nozzles were replaced by the whirlpool-disk type nozzles, except in plats XIV and XV, which were treated by the owner. In plat XIV the use of the Bordeaux nozzles was continued, for the cover applications, throughout the season; in plat XV a spray gun, operated from the ground, was employed for all cover sprays.

TABLE 8.—*Spraying schedule for codling moth, Smith orchard, Grand Valley of Colorado, 1917.*

Number of plat.	Calyx spray.	Cover sprays, first brood.				Cover sprays, second and third broods.			
	A.	B.	C.	D.	E.	F.	G.	H.	I.
	Petals off May 24-29.	19 to 22 days after A, June 12-15.	11 to 13 days after B, June 23-25.	16 days after B, June 28.	10 to 13 days after C, July 3-6.	8 weeks after A, July 18-20.	27 days after F, Aug. 14.	36 days after F, Aug. 23-25.	21 days after G, Sept. 4.
I.....	First.....	Second..	Third...		Fourth..	Fifth....		Sixth..	Sev-enth.
II.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
III.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
IV.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
V.....	do.....	do.....	.....	Third..	Fourth..	Fourth..	.....	Fifth..	
VI.....	do.....	do.....	Third..	.....	Fifth..	Fifth..	.....	Sixth..	
VII.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
VIII.....	do.....	do.....	Third..	.....	Fourth..	Fourth..	.....	Fifth..	
IX.....	do.....	do.....	Third..	.....	Fourth..	Fifth....	Sixth..	.....	
X.....	Calyx spray omitted.	First....	Second..	.....	Third....	Fourth..	.....	Fifth....	
XI.....	First.....	Second..	Third....	.....	Fourth..	Fifth....	.....	Sixth..	
XII.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XIII.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XIV.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XV.....	do.....	do.....	do.....	.....	do.....	do.....	.....	do.....	
XVI.....	Check—un-sprayed.	.....	.....	.....	.....	.....	.....	.....	
XVII.....	do.....	.....	.....	.....	.....	.....	.....	.....	

TABLE 9.—*Treatment of plats for codling moth, Smith orchard, Grand Junction, Colo., 1917.*

Number of plat.	Spray materials and supplemental control measures.	Spraying and dusting equipment.	
		Calyx spray.	Cover sprays.
I.....	Arsenate of lead, powder, 1 pound—50, and codling moth traps.	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool-disk nozzles.
II.....	Arsenate of lead, powder, 1 pound—50.	do.....	Do.
III.....	Nicotine sulphate, 40 per cent, $\frac{1}{2}$ pint—50.	do.....	Do.
IV.....	Arsenate of lead, powder, 1 pound—50, and nicotine sulphate, 40 per cent, $\frac{1}{2}$ pint—50.	do.....	Do.
V.....	Arsenate of lead, powder, 1 pound—50, and codling moth traps.	do.....	Do.
VI.....	Arsenate of lead, powder, 1 pound—50, and fish-oil soap, 2 pounds—50.	do.....	Do.
VII.....	Arsenate of lime, powder, $\frac{3}{4}$ pound—50.	do.....	Do.
VIII.....	Arsenate of lead, powder, 1 pound—50.	do.....	Do.
IX.....	do.....	do.....	Do.
X.....	do.....	Calyx spray omitted.	Do.
XI.....	Arsenate of lead, 20 per cent, and hydrated lime, 80 per cent.	Power dusting machine.	Power dusting machine.
XII.....	Arsenate of lead, 15 per cent, and hydrated lime, 85 per cent.	do.....	Do.
XIII.....	Arsenate of lead, 10 per cent, and hydrated lime, 90 per cent.	do.....	Do.
XIV.....	Arsenate of lead, powder, 1 pound—50.	Spray poles and Bordeaux nozzles.	Spray poles and Bordeaux nozzles.
XV.....	do.....	do.....	Spray gun.
XVI.....	Check—unsprayed.	.....	.....
XVII.....	do.....	.....	.....

All the plats, except the unsprayed checks and plat X, were given the calyx treatment. The total number of applications varied from five to seven, with six in the majority. Plats I, II, III, and IV were given the same number of applications, three cover sprays for the first brood and two for the second and third broods. Plats V and VIII had but four cover sprays of lead arsenate, two for the first brood and two for the later broods, and in addition plat V was provided with the codling-moth trap applied to each tree. Plats VI and VII were sprayed throughout the season at the same time as plats I to IV, but, as described later, received different treatment. Plat IX received the largest number of applications, three cover sprays for the first brood and the same number for the second and third broods, making a total of six cover treatments. Plat X was given five cover sprays, but, as previously mentioned, the calyx treatment was omitted. Plats XI, XII, and XIII were given treatment at the same time as the other plats having five cover applications, but the dusting method was substituted for the liquid.

Arsenate of lead, powder, at the rate of 1 pound to 50 gallons of water was used in all of the sprayed plats, except plat VII, in which arsenate of lime, powder, three-fourths pound to 50 gallons, was employed, and plat III, where 40 per cent nicotine sulphate, diluted 1 part in 800 parts of water, was used. Forty per cent nicotine sulphate at this strength was also used with arsenate of lead in plat IV, and in plat VI fish-oil soap, 2 pounds to 50 gallons, was used as a spreader and sticker. Codling-moth traps, described on pages 35-38, were used in plats I and V. Plats XI, XII, and XIII were dusted with arsenate of lead mixed with hydrated lime as a filler in the proportions shown in Table 9. In plat XI a dust mixture containing 20 per cent of arsenate of lead and 80 per cent of hydrated lime was used; in plat XII, the arsenate of lead was decreased to 15 per cent and the hydrated lime increased to 85 per cent. Plat XIII was treated with 10 per cent of arsenate of lead and 90 per cent of hydrated lime. Plats XIV and XV were sprayed by the owner with arsenate of lead and, as previously stated, plats XVI and XVII were untreated throughout the season.

The summary of results of these experiments is presented in Table 10.

Plat VI, which was sprayed six times with arsenate of lead and fish-oil soap, yielded 78.06 per cent of apples free from worms, which was the highest percentage of uninfested fruit in the orchard. Also the average number of worms for all apples was as low in this plat as in any other. The percentage of all apples free from worms and stings in plat VI was 46.22, which was not as high as that obtaining in plats IX (46.44 per cent), V (47.84 per cent), and IV (49.82 per cent). Plat IX produced the next best results, 76.53 per cent of all the fruit being free from worms as a result of seven applications of arsenate of lead; plat V, with five treatments supplemented with the codling-moth trap, yielded 72.29 per cent of uninfested fruit; plat IV, 72.05 per cent, with six applications of arsenate of lead and nicotine sulphate. Two other plats, I and VIII, produced 70.99 and 73.49 per cent of worm-free fruit, respectively; the former being sprayed six times with arsenate of lead, supplemented with the codling-moth trap, and the latter having only five applications of arsenate of lead. Plat II, which received six applications of arsenate of lead, yielded but 62.10 per cent of worm-free fruit and but 27.04 per cent of fruit free from worms and stings. Apparently the infestation in this plat was somewhat heavier than that which prevailed in some of the other plats. Plat III was treated six times with nicotine sulphate, which resulted in but 37.97 per cent of fruit free from worms. The percentage of this fruit free from stings was relatively high (88.62 per cent), a condition which would naturally be expected, owing to the fact that the majority of the larvæ that attacked the fruit were able to enter it without being killed by the spray. Attention is called to the fact that in this plat (plat III) 18.07 per cent of all the worms infesting the apples entered by way of the calyx end and that 22.39 per cent of the wormy apples were infested at the calyx. In plat VII arsenate of lime was used with unsatisfactory results, there being 36.51 per cent of worm-free apples and only 20.33 per cent of the fruit free from worms and stings. Plat X was sprayed at the same time as the plats that had six treatments, except that the calyx application was omitted, thus making a total of five treatments. The percentage of worm-free fruit was 46.33, and the percentage of all apples free from worms and stings was 25.36. It is worthy of note that the percentage of worms entering the calyx was high (29.83 per cent), and that 37.42 per cent of the wormy apples were infested at the calyx.

Plats XI, XII, and XIII were dusted six times with mixtures containing 20, 15, and 10 per cent of arsenate of lead, respectively. The results of these treatments indicate quite conclusively that dusting is unsatisfactory for the control of the codling moth in the Grand Valley. With as much as a 20 per cent lead arsenate mixture only 40.75 per cent of the fruit was free from worms; with a 15 per cent lead arsenate mixture there was 34.58 per cent of worm-free fruit;

and with a mixture containing 10 per cent of lead arsenate there was only 14.38 per cent of uninfested fruit, all of which would indicate practically no control. Furthermore, the dust was not nearly so effective as the liquid sprays in preventing the entrance of worms at the calyx.

The two plats sprayed by the grower, plats XIV and XV, produced a lower percentage of control than those treated by the experimental staff. Plat XIV, in which spray poles and Bordeaux nozzles were used throughout the season, yielded 40.21 per cent of uninfested fruit, whereas plat XV, in which the spray gun was employed for the cover sprays, gave but 30.22 per cent of worm-free fruit.

The abundance of the codling moth in this orchard is indicated in plats XVI and XVII, both of which were untreated and which produced but 8.83 and 8.54 per cent of worm-free fruit. The number of stings in these plats, as was to be expected, was not large, there being 88.16 per cent of fruit free from stings in plat XVI and 87.42 per cent in plat XVII. It will be further noted that in these plats the percentage of calyx worms was large, 30.26 and 28.92 per cent, respectively, with 47.09 and 47.50 per cent of the wormy apples infested at the calyx end.

CODLING-MOTH TRAP EXPERIMENTS IN 1917.

A section of the J. B. Hunter orchard near Fruitā, Colo., consisting of Ben Davis and Gano apple trees, was divided into three plats. Plat I, containing 60 trees, was banded and sprayed; plat II, having 108 trees, was provided with the codling-moth trap and sprayed; while plat III, 99 trees, received no other treatment than five spray applications as described below.

The spray applications, five in all, were made by the grower on all the plats as follows: Calyx spray applied June 1-2; first cover spray June 14-16; second cover spray July 11; third cover spray July 27; fourth cover spray August 16. A power sprayer was used throughout the season and this was equipped with Bordeaux nozzles for the calyx application and whirlpool-disk type nozzles having a large aperture disk for all of the cover treatments.

The data obtained from the examination of the dropped and harvested fruit from eight trees in each plat will be found in Table 11. It will be noted therein that plat III, which had only the spray treatment, produced 76.56 per cent of fruit free from worms, a higher percentage than that of plats I and II, which received theoretically better treatments. There is no logical explanation for these results other than the possibility of unevenness of infestation and yield of fruit.

TABLE 11.—Summary of results of spraying for the codling moth, Hunter orchard, Grand Valley of Colorado, 1917.

Plat.	Num- ber of trees ex- amined.	Total num- ber of apples ex- amined.	Total num- ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.			Aver- age num- ber of stings for all apples.	Aver- age num- ber of stings free from stings.	Per- cent- age of wormy apples free from stings.	Per- cent- age of all apples free from worms and stings.	Per- cent- age of all apples free from worms and stings.	Per- cent- age of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.						
I.....	8	24,345	13,446	0.55	16.91	81.91	1.18	21.95	77.01	1.04	0.63	1.59	57.98	62.76	57.44	26.04
II.....	8	38,781	15,209	.89	30.43	68.10	1.47	39.79	59.06	1.15	.33	1.37	74.73	76.13	70.00	53.29
III.....	8	45,689	14,056	.31	22.52	75.82	1.66	29.57	68.81	1.62	.35	1.38	71.19	76.09	76.56	58.26

NOTE.—See p. 16 for treatments.

TABLE 12.—Collections of codling moth larvae and pupae from banded trees, Plat I, Hunter orchard, Grand Valley of Colorado, 1917.

Tree No.	Date of collection.																
	July 3.		July 12.		July 18.		July 28.		Aug. 7.		Aug. 17.		Aug. 27.		Sept. 6.		Nov. 21, larvæ.
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.			
1.	6		21	7	21		17	7	10	5	10		20		13		44
2.	12		31	7	14	3	20	8	6	5	11	3	10		9		48
3.	58	1	55	17	27	3	33	5	10	2	20	2	10		14		67
4.	11		29	6	17	1	18	6	2	1	3		11		20		34
5.	5		36	3			15	7	6	2	11	2	9		19		37
6.		1	29		18	2	4	3	19	2	7	5	16		8		28
7.	3	1	2	3	10		8	8	6	2	2	2	4		8		27
8.	2		10		9	3	13	7	8	6	16	1	7		24		26
9.	2		22	14	30	1	22	6	9	12	28	7	14		13		47
10.	12		20	2	21	1	37	8	15	3	32	5	11		37		38
11.	7		10	4	11	2	12	3	9	7	18	4	4		4		16
12.	23		18	12	31	4	13	8	6	4	8	3	8		9		26
13.	5		27	4	36	5	25	8	12	6	12	3	8		15		25
14.			18	2	6		14	9	3	4	3	3	4		2		36
15.	1	1	6	3	27	2	10	7	8	5	10	8	13		7	2	25
	1		8	3	12	2	6	4	6	8	9	1	5		4		16

TABLE 12.—Collections of codling moth larvae and pupæ from banded trees, Plat I, Hunter orchard, Grand Valley of Colorado, 1917.—Continued.

Tree No.	Date of collection.												Nov. 21, larvæ.				
	July 3.		July 12.		July 18.		July 28.		Aug. 7.		Aug. 17.			Aug. 27.		Sept. 6.	
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.		Larvæ.	Pupæ.	Larvæ.	Pupæ.
17	15	1	12	4	10	6	6	2	11	6	17	2	11	11	14	-----	43
18	2	-----	12	3	17	2	7	7	2	5	26	3	3	21	18	-----	54
19	1	-----	8	3	13	-----	5	5	6	4	15	1	5	20	19	-----	52
20	1	-----	6	1	8	-----	1	10	7	13	16	2	2	10	13	-----	35
21	2	-----	21	6	24	2	16	11	6	5	33	4	4	12	15	-----	38
22	2	-----	24	7	12	-----	14	5	10	5	24	4	2	16	15	-----	46
23	2	-----	13	1	24	-----	4	12	6	2	10	1	2	9	11	-----	18
24	2	-----	17	-----	10	2	3	8	2	1	13	-----	6	6	26	-----	13
25	10	-----	9	-----	17	-----	6	5	5	3	8	3	4	5	21	-----	15
26	4	-----	23	7	13	-----	15	3	3	3	21	2	2	5	25	-----	10
27	10	-----	1	12	10	-----	15	13	2	5	12	1	12	11	1	-----	30
28	1	-----	3	-----	2	-----	5	4	8	5	14	2	6	7	7	-----	21
29	6	-----	24	11	29	-----	17	6	9	2	16	2	22	12	12	-----	47
30	28	-----	28	15	34	-----	7	8	12	8	16	4	4	11	37	-----	37
31	13	-----	9	6	33	-----	4	13	5	7	21	4	4	16	22	-----	19
32	15	-----	47	13	19	-----	2	23	7	12	35	15	1	15	15	-----	49
33	5	-----	1	16	6	-----	10	-----	4	2	15	1	1	12	19	-----	20
34	5	-----	1	7	16	-----	15	7	7	2	38	3	18	22	30	-----	30
35	11	-----	26	11	13	-----	24	9	7	4	34	2	12	24	40	-----	40
36	2	-----	15	6	14	-----	3	1	3	2	16	5	16	1	3	-----	68
37	2	-----	5	-----	5	-----	-----	5	3	-----	5	2	2	8	8	-----	12
38	14	-----	13	5	11	-----	7	16	9	7	20	3	10	18	29	-----	29
39	12	-----	10	6	11	-----	4	14	17	7	8	3	5	10	52	-----	52
40	2	-----	9	2	6	-----	4	7	6	5	11	3	6	10	20	-----	20
41	1	-----	7	2	17	-----	3	10	5	5	16	2	12	1	6	-----	29
42	2	-----	9	5	6	-----	15	2	5	6	11	3	9	12	2	-----	21
43	13	-----	1	16	6	-----	18	5	6	3	6	1	4	12	10	-----	12
44	3	-----	20	6	7	-----	1	10	6	5	11	-----	22	1	10	-----	10
45	3	-----	38	16	18	-----	7	18	5	12	7	4	2	7	7	-----	23
46	7	-----	32	10	9	-----	2	18	4	8	6	1	2	5	18	-----	18
47	4	-----	10	3	3	-----	3	4	6	2	4	2	3	9	15	-----	15
48	2	-----	14	5	13	-----	3	11	10	-----	4	-----	2	5	5	-----	7
49	-----	-----	3	-----	1	-----	1	1	-----	1	1	-----	2	2	3	-----	6
50	5	-----	11	13	9	-----	1	8	5	2	3	2	1	4	4	-----	11
51	9	-----	46	30	25	-----	4	35	19	3	13	5	17	13	32	-----	32
52	12	-----	4	27	14	-----	14	13	10	3	27	8	12	35	13	-----	13
53	8	-----	1	19	7	-----	26	11	14	9	13	7	13	19	25	-----	25
54	11	-----	42	38	20	-----	37	18	13	6	19	7	1	27	35	-----	35

TABLE 13.—*Collections from codling moth traps, Plat II, Hunter orchard, Grand Valley of Colorado, 1917.*

Tree No.	Date of collection.											
	July 12.		July 18.		July 28.		Aug. 7.		Aug. 17.		Aug. 27.	
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.
1.....	15	12	24	2	16	31	12	3	5	2	15	8
2.....	27	6	25	4	6	17	11	4	15	2	24	19
3.....	33	21	26	5	27	27	6	8	11	6	18	43
4.....	10	17	18	5	13	14	10	10	5	2	9	20
5.....	36	5	30	5	15	14	5	5	12	6	24	42
6.....	9	3	15	5	14	20	5	2	15	1	19	20
7.....	25	2	19	5	20	22	10	7	10	1	15	13
8.....	24	16	19	3	6	21	3	4	3	1	9	19
9.....	9	7	11	1	13	10	8	4	4	1	3	36
10.....	12	11	14	1	15	15	6	6	10	1	21	33
11.....	16	3	27	7	14	12	6	8	10	2	17	28
12.....	9	5	17	1	17	16	5	2	5	2	10	20
13.....	16	5	17	5	14	14	5	2	8	2	10	6
14.....	17	12	25	4	20	21	9	6	10	2	15	19
15.....	24	13	28	3	10	20	12	4	7	3	14	22
16.....	6	2	6	2	5	9	5	5	3	1	5	15
17.....	6	6	10	2	7	8	5	5	4	1	7	7
18.....	12	3	17	2	15	10	5	5	4	4	5	5
19.....	11	2	15	1	22	21	11	7	17	1	15	16
20.....	7	3	6	2	12	24	7	3	7	1	8	10
Total.....	400	46	1,069	412	867	130	818	436	385	250	792	814
											164	9
											547	3
Total number larvæ for season.....	7,355											
Total number pupæ for season.....	1,450											
	Total number all stages for season.....											
	Average number all stages per tree.....											
	8,805											
	157.23											

Total number larvæ for season.....	3,941
Total number pupæ for season.....	687
Total number moths for season.....	2
	Total number all stages for season.....
	Average number all stages per tree.....
	197.05

In Tables 12 and 13 will be seen the data obtained from examinations of the bands and traps. From 56 banded trees 8,805 larvæ and pupæ, or an average of 157.23, were taken, and from 20 codling-moth traps 3,941 larvæ, pupæ, and moths, or an average of 197.05, were secured. The destruction of so large a number of individuals should aid gradually in obtaining better control despite the fact that the experimental data for this, the first year, indicate otherwise.

Part of the orchard of Charles Lamb near Highland Park was also used for the codling-moth trap experiments. This was sprayed by the grower who used the short rod equipped with a Bordeaux type of nozzle in making all the spray applications. In addition to the calyx treatment, six cover sprays were applied. Plat I was sprayed and trapped, plat II was sprayed, and plat III was untreated.

The results of the fruit examinations of eight trees in each of plats I and II and four trees in plat III are given in Table 14. In plat I, which was sprayed and trapped, 50.54 per cent of the dropped and harvested fruit was free from worm infestation; whereas in plat II, which was merely sprayed, there was 64.54 per cent of uninfested fruit. The unsprayed plat produced 11.45 per cent of fruit free from larvæ.

It will be noted in Table 15 that 5,512 larvæ, pupæ, and moths were collected from 20 codling-moth traps and that the average per trap was 275.6.

In the Smith experimental orchard, where the principal spraying experiments of 1917 were conducted, examinations were made of 20 codling-moth traps in plat I and of 15 in plat V. The results are presented in Tables 16 and 17, in which it will be seen that in plat I, 6,186 larvæ, pupæ, and moths, or an average of 309.3 per trap, were secured, while in plat V a total of 4,673 or an average per trap of 311.53 individuals were captured.

TABLE 14.—Summary of results of spraying for the codling moth, Lamb orchard, Grand Valley of Colorado, 1917.

Plat.	Num- ber of trees ex- amin- ed.	Total num- ber of apples ex- amin- ed.	Total num- ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.			Total num- ber of stings.	Aver- age num- ber of stings for all apples.	Aver- age num- ber of stings for stung apples.	Per- centage of wormy apples free from stings.	Per- centage of all apples free from worms, stings.	Per- centage of all apples free from worms, stings.	Per- centage of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.							
I.....	8	15,380	9,544	0.62	3.51	95.32	1.17	4.40	94.35	1.25	10,672	0.69	1.59	66.63	50.54	56.62	23.69
II.....	8	20,578	8,386	.42	3.27	93.12	1.61	6.21	92.21	1.58	14,003	.68	1.72	67.90	64.54	60.35	36.28
III.....	4	8,949	11,752	1.31	24.99	73.69	1.32	37.11	61.56	1.33	1,381	.15	1.23	87.57	11.45	87.42	9.57

NOTE.—See page 21 for treatments.

TABLE 16.—*Collections from codling moth traps, plat I, Smith orchard, Grand Valley of Colorado, 1917.*

Tree No.	Date of collection.																		
	July 7.		July 17.		July 27.		Aug. 6.		Aug. 16.		Aug. 26.		Sept. 5.		Nov. 20. larvæ.				
	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Larvæ.	Pupæ.	Moths.	Larvæ.	Pupæ.	Moths.	Larvæ.	Pupæ.	Moths.	Larvæ.		Pupæ.			
1.	14	1	10	24	12	15	9	13	10	8	52	61	152						
2.	10	3	30	30	13	22	22	20	26	7	33	74	238						
3.	5	3	14	13	10	11	6	5	7	6	26	82	195						
4.	30	5	35	58	20	30	6	18	17	6	42	93	192						
5.	25	3	30	42	6	20	1	3	6	4	2	67	121						
6.	15	1	29	40	14	11	5	3	17	6	1	44	121						
7.	10	6	15	14	5	9	5	4	8	1	28	66	148						
8.	8	3	5	11	8	8	7	5	12	2	42	74	168						
9.	3	1	1	17	2	6	4	5	11	3	27	56	116						
10.	2	1	15	23	8	11	6	5	10	2	38	57	158						
11.	7	1	7	4	1	1	1	1	4	4	21	32	71						
12.	7	1	24	30	3	12	2	2	6	1	28	48	126						
13.	4	1	13	6	3	5	1	3	7	1	34	64	140						
14.	8	1	15	25	5	4	2	3	7	3	18	57	167						
15.	10	4	13	19	2	3	7	2	2	3	25	30	118						
16.	6	3	7	16	2	9	1	1	2	1	26	39	126						
17.	2	4	10	13	4	7	1	3	2	1	12	41	77						
18.	3	3	6	3	3	4	3	1	2	1	12	45	115						
19.	5	1	12	13	2	4	1	3	1	1	3	79	79						
20.	17	4	2	26	7	12	2	9	5	1	25	67	162						
Total number larvæ for season.....																5,326	Total number all stages for season.....		6,186
Total number pupæ for season.....																845	Average number all stages per tree.....		369.3
Total number moths for season.....																15			

As will be noted in Table 10, plat I yielded 70.99 per cent of fruit free from worms, an improvement in favor of the traps over plat II, which was untrapped but received the same number of spray applications (six in all) and which yielded 62.1 per cent of worm-free fruit. On the other hand, the traps did not improve the results in plat V, which, like plat VIII, received a total of five applications, the yield of worm-free fruit in these two plats being 72.29 per cent and 73.49 per cent, respectively.

From the foregoing experiments it will be seen that the traps captured an average of from 197.05 to 311.53 individuals per tree; but contrary to what might be expected, the reduction in the number of insects was not generally followed by a corresponding decrease in the percentage of wormy fruit. This would appear illogical, and it will therefore be necessary to make further tests covering a longer period of time before the value of the codling-moth traps as a supplementary control measure can be determined.

SPRAYING EXPERIMENTS IN 1918.

The spraying experiments in 1918 were conducted in the Red Cross orchard on a block of Gano trees about 13 years of age. These trees were subdivided into 12 plats, of which 10 were sprayed and the remaining 2 were untreated checks located in diagonally opposite corners of the orchard.

Table 18 shows the treatment given in the different plats. Arsenate of lead, powder, at the rate of 1 pound to 50 gallons was used in all of the sprayed plats, except in plats IX and X where the strength was reduced to one-half pound to 50 gallons. Fish-oil soap at the rate of 2 pounds to 50 gallons was used as a spreader and sticker for the arsenate of lead in plats III, IV, VII, VIII, and IX. The codling-moth trap was applied to all trees in plats I, III, V, and VII.

The sprays were applied by means of a power sprayer delivering about 225 pounds' pressure to two leads of hose. Two spray poles were employed in all treatments, one being operated from the tower and the other from the ground. In the calyx application Bordeaux nozzles were used, but these were replaced by whirlpool disk nozzles for the cover sprays.

As shown in Table 19, plats I to IV received, in addition to the calyx treatment, five cover sprays, three for the first brood and two for the later broods, and plats V to X were given one less cover spray, making a total of four, two of which were applied for the first-brood larvæ and two for protection against the second and third broods.

TABLE 18.—*Treatment of plats for the codling moth, Red Cross orchard, Grand Valley of Colorado, 1918.*

No. of plat.	Spray materials and supplemental control measures.	Spraying equipment.	
		Calyx spray.	Cover sprays.
I.....	Arsenate of lead, powder, 1 pound—50, and codling-moth traps.	Spray poles and Bordeaux nozzles.	Spray poles and whirlpool disk nozzles.
II.....	Arsenate of lead, powder, 1 pound—50.	do.....	Do.
III.....	Arsenate of lead, 1 pound—50, fish-oil soap, 2 pounds—50, and codling-moth traps.	do.....	Do.
IV.....	Arsenate of lead, 1 pound—50, and fish-oil soap, 2 pounds—50.	do.....	Do.
V.....	Arsenate of lead, powder, 1 pound—50, and codling-moth traps.	do.....	Do.
VI.....	Arsenate of lead, powder, 1 pound—50.	do.....	Do.
VII.....	Arsenate of lead, 1 pound—50, fish-oil soap, 2 pounds—50, and codling-moth traps.	do.....	Do.
VIII....	Arsenate of lead, 1 pound—50, and fish-oil soap, 2 pounds—50.	do.....	Do.
IX.....	Arsenate of lead, $\frac{1}{2}$ pound—50, and fish-oil soap, 2 pounds—50.	do.....	Do.
X.....	Arsenate of lead, $\frac{1}{2}$ pound—50.	do.....	Do.
XI.....	Check—unsprayed.		
XII.....	do.		

TABLE 19.—*Spraying schedule for the codling moth, Red Cross orchard, Grand Valley of Colorado, 1918.*

No. of plat.	Calyx spray.	Cover sprays—first brood.				Cover sprays—second and third broods.	
	A.	B.	C.	D.	E.	F.	G.
	Petals off, May 10-14.	3 to 4 weeks after A, June 3-5.	9 days after B, June 12-13.	12 days after B, June 15-17.	11 days after C, June 23-24.	8 to 9 weeks after A, July 8-11.	35 days after F, Aug 12-15.
I.....	First.....	Second.....	Third.....		Fourth.....	Fifth.....	Sixth.
II.....	do.....	do.....	do.....		do.....	do.....	Do.
III.....	do.....	do.....	do.....		do.....	do.....	Do.
IV.....	do.....	do.....	do.....		do.....	do.....	Do.
V.....	do.....	do.....		Third.....		Fourth.....	Fifth.
VI.....	do.....	do.....		do.....		do.....	Do.
VII.....	do.....	do.....		do.....		do.....	Do.
VIII....	do.....	do.....		do.....		do.....	Do.
IX.....	do.....	do.....		do.....		do.....	Do.
X.....	do.....	do.....		do.....		do.....	Do.
XI.....	Check.....						
XII.....	do.....						

The results of these experiments are summarized in Table XX. The best results were obtained in plat IV in which 77.36 per cent of the fruit was free from worms and 60.36 per cent was free from both worms and stings. This plat was sprayed six times with arsenate of lead and fish-oil soap. Plat III, which had a like number of applications of the same materials and in addition was provided with the codling-moth trap, yielded 71.80 per cent of fruit free from worms and only 42.78 per cent free from both worms and stings. None of the other plats produced satisfactory commercial returns, and in plat VIII, which was sprayed five times with arsenate of lead and fish-oil soap, but 21.23 per cent of fruit was free from

worm infestation. Plat VI, which was given five applications of arsenate of lead alone, produced 37.88 per cent of fruit free from worms. It will thus be seen that in these experiments the addition of soap did not in all cases increase the percentage of worm-free apples, nor did the codling-moth trap appear to have any distinct value. In plats IX and X the arsenate of lead strength was reduced to one-half pound to 50 gallons, and, all factors being taken into consideration, the results indicate that this strength is as effective as 1 pound to 50 gallons. The unsprayed plats XI and XII produced 8.43 and 24.08 per cent of worm-free fruit, respectively.

The percentage of calyx entrants was somewhat higher in the unsprayed than in the sprayed fruit, but the difference in this respect is not so great as is usually found in spraying experiments for the control of the codling moth. The unsprayed fruit was comparatively free from the codling-moth sting, which is in accord with the experimental data obtained in the preceding years.

TABLE 20.—*Summary of spraying results for the codling moth, Red Cross orchard, Grand Valley of Colorado, 1918.*

Plat.	Num-ber of trees ex-amin-ated.	Total num-ber of apples ex-amin-ated.	Total num-ber of worms (includ- ing extra).	Aver- age num- ber of worms for all apples.	Percentage of worms (including extra) en- tering apples.			Percentage of wormy apples infested.			Aver- age num- ber of stings for all apples.	Aver- age num- ber of wormy apples free from stings.	Per- centage of all apples free from worms and stings.	Per- centage of all apples free from worms and stings.	Per- centage of all apples free from worms and stings.	Per- centage of all apples free from worms and stings.
					At calyx.	At side.	At stem.	At calyx.	At side.	At stem.						
I.....	8	8,466	5,402	0.64	6.67	92.98	0.35	9.94	89.54	0.52	2.90	36.73	59.15	57.22	49.56	33.85
II.....	8	8,390	5,828	0.69	7.15	92.49	.36	11.76	87.99	.25	3.46	35.78	71.15	57.72	43.80	41.07
III.....	8	7,413	2,855	.39	14.15	85.08	.77	19.33	79.71	.96	2.06	46.69	59.57	71.80	55.94	42.78
IV.....	8	9,478	3,096	.33	10.14	89.67	.19	14.64	85.13	.23	3.41	41.49	78.02	77.36	69.51	60.36
V.....	8	9,820	10,301	1.05	7.27	92.34	.39	12.53	87.07	.40	2.66	48.54	80.68	39.11	61.10	31.56
VI.....	8	4,318	5,196	1.20	6.68	93.19	.13	12.94	86.91	.15	4.20	32.48	61.12	37.88	43.33	23.16
VII.....	8	5,847	3,266	.90	9.84	89.88	.28	15.77	84.05	.18	3.31	46.50	63.69	43.80	54.03	27.89
VIII.....	8	2,628	4,768	1.81	8.18	91.48	.34	18.84	80.82	.34	3.74	51.26	92.47	21.23	60.00	19.63
IX.....	8	3,145	3,080	.98	10.00	89.61	.39	17.31	82.35	.34	4.45	37.27	69.47	43.43	51.22	30.17
X.....	8	5,348	5,201	.97	9.55	89.68	.77	17.39	81.67	.94	3.49	57.38	94.84	46.55	74.83	44.17
XI.....	8	2,489	4,549	1.83	16.73	82.26	1.01	33.39	65.86	.75	1.32	91.79	99.05	8.43	92.40	8.36
XII.....	4	3,343	4,849	1.42	12.87	86.57	.56	24.59	75.02	.39	1.27	91.09	99.63	24.08	93.15	23.99

SUMMARY OF RESULTS.

The principal points of interest in connection with the experimental spray work in the Grand Valley of Colorado may be briefly summarized as follows:

SEASON OF 1915.

The highest percentage of fruit free from worms obtained in the experimental plats in 1915 was 72.22, in a plat which received six applications of arsenate of lead paste, 2 pounds to 50 gallons. In the unsprayed plat there was but 13.51 per cent of worm-free fruit. Arsenate of lime, both homemade and commercial, gave poorer control than arsenate of lead. In the control of larvæ that attempt to enter the fruit by way of the calyx cavity the results indicate that a low-pressure fine mist spray is as effective as a high-pressure coarse spray. The number of stings per apple was considerably less in the unsprayed than in the sprayed fruit.

SEASON OF 1916.

The best result during the season of 1916, 89.7 per cent of the fruit free from worm infestation, was obtained in a plat sprayed four times with arsenate of lead powder, 1 pound to 50 gallons. In the unsprayed plat 30.98 per cent of the fruit was uninfested. The primary object of the season's work was to test a coarse spray applied by means of a short rod equipped with a Bordeaux nozzle in comparison with a fine spray applied with spray poles and whirlpool-disk type nozzles. The results indicate that better control was secured with the finer sprays applied with the spray poles.

SEASON OF 1917.

The highest percentage of fruit free from worms in 1917 was 78.06, as a result of six applications of arsenate of lead, 1 pound of the powder to 50 gallons of water, to which fish-oil soap was added at the rate of 2 pounds to 50 gallons. Two unsprayed plats yielded 8.83 and 8.54 per cent of fruit free from worms. Another plat sprayed with six applications of arsenate of lead, but without fish-oil soap, produced 62.10 per cent of worm-free fruit, thus indicating that the addition of a soap spreader was of some value. The results with the codling-moth trap did not indicate that it materially aided in the control of the codling moth during the time of the experiments. Nicotine sulphate gave poor control and in combination with arsenate of lead apparently had very little value in reducing worm infestation or sting injury. Arsenate of lime gave unsatisfactory results. The dust treatments were even more ineffective. The plat in which the calyx spray was omitted was heavily infested at the calyx end. Five spray applications produced practically as much good fruit as seven.

SEASON OF 1918.

In 1918 in a plat sprayed six times with arsenate of lead and fish-oil soap at the usual strengths 77.36 per cent of the fruit was free from worms, this being the highest percentage of worm-free fruit obtained during the season. In two untreated plats, 8.43 and 24.08 per cent of fruit were free from worm infestation. The use of fish-oil soap in combination with arsenate of lead gave somewhat variable results. The codling-moth trap was of little value as a supplemental control measure. Arsenate of lead powder, one-half pound to 50 gallons, was about as effective as when used at twice this strength.

SUGGESTIONS FOR THE CONTROL OF THE CODLING MOTH IN THE GRAND VALLEY OF COLORADO.

The experience of the writers and others who are acquainted with Grand Valley conditions indicates that the codling moth presents a very difficult problem. As previously stated, there are two full broods of larvæ per annum and a partial third brood. The moth is extremely prolific because of the warm dry climate, and, as a result, the apples are exposed to large numbers of newly hatching larvæ practically every day during the development of the fruit.

The primary object of spraying is to cover the fruit and foliage with poison, and when this is properly distributed good protection is obtained for a time. It is, however, quite impossible in commercial spraying to coat completely all parts of the fruit, and further, as the apple develops in size it gradually outgrows the spray residue. The result is, that with numerous larvæ seeking a place of entrance, some will start feeding where there is no poison, gain entrance, and thus produce wormy apples. It is not commercially profitable to spray too many times during the season, but a sufficient number of applications should be made at such intervals as constantly to provide a protective coating of poison on the fruit, particularly when the larvæ are hatching in large numbers.

As a result of the life-history investigations in the Grand Valley and other places, it has been found that the development of the codling moth from the time of hatching of the first eggs of the season does not as a rule vary to any great extent and that an average can be struck which, over a series of years, would usually represent the approximate development of the insect with sufficient accuracy for spraying purposes.

Some growers of the Grand Valley have attempted to ascertain the time to spray by making observations in the orchard, such as inspection of the leaves for eggs and of the fruit for newly entered larvæ. The writers are inclined to believe that this particular method as practiced by the fruit grower is unreliable and frequently misleading, although regular and systematic inspections over a considerable

portion of the orchard will sometimes give information of value. As a rule, however, fruit growers have neither the time nor patience to undertake a careful orchard survey. On account of seasonal variations, calendar dates for making applications can not be depended upon, but a schedule based on certain intervals following the dropping of the blossom petals will usually result in timely spraying.

In formulating the control of the codling moth it is very important that the approximate time of the first hatching of each brood of larvæ and the relative number of worms that are developing from time to time be known. Complete and reliable data of this nature were obtained in the foregoing life-history studies, and with these data at hand it is believed that the most effective time for making the spray applications can be established.

The spray schedules that follow are based on the life-history studies of 1915 and 1916 and take into consideration the time when each brood begins to hatch, the time when the larvæ are hatching in large numbers, as well as the time when hatching occurs in maximum numbers. Three sets of schedules, I, II, and III, all starting from the time 90 per cent of the petals have dropped, are presented in Table 21, by reference to which it will be seen that schedule I calls for five applications and is intended for orchards having a relatively light infestation and for varieties on which the codling moth is not difficult to control; schedule II, six applications, for a medium infestation and for varieties on which the codling moth is moderately difficult to control; schedule III, seven applications, for a heavy infestation and for varieties on which the codling moth is most difficult to control.

The codling moth is normally abundant in the Grand Valley, and apples such as the Ben Davis, Schackelford, and other susceptible varieties will usually require schedule III, or seven treatments, especially if from previous neglect or other cause the infestation is very heavy; whereas, under similar conditions of infestation, varieties like the Winesap, on which the codling moth is more readily controlled, will require a smaller number of applications, as in schedules I or II. The degree of infestation varies somewhat from year to year and in the different fruit districts, and, as previously stated, the control of this insect varies with the different varieties. For these reasons, no one schedule will meet the demands of all the growers, and it will be necessary for each individual to forecast in advance what his conditions are likely to be and spray accordingly.

TABLE 21.—*Spraying schedules for the codling moth in the Grand Valley of Colorado.*

Application.	Spray application.	Time of application.	Applications.		
			I.	II.	III.
			Light infestation and with varieties on which the codling moth is not difficult to control.	Medium infestation and with varieties on which the codling moth is moderately difficult to control.	Heavy infestation and with varieties on which the codling moth is difficult to control.
Calyx spray.....	A.	Begin when 90 per cent petals have dropped and finish before calyces close.	First.....	First.....	First.
Cover spray, first brood.	B.	3 to 4 weeks after A, just previous to time when first-brood larvæ begin to hatch.	Second....	Second....	Second.
Do.....	C.	10 to 12 days after B, just previous to hatching of first-brood larvæ in large numbers.	.....	Third.....	Third.
Do.....	D.	15 to 17 days after B, just previous to hatching of first-brood larvæ in maximum numbers.	Third.....	.....	.....
Do.....	E.	10 to 12 days after C, for late hatching first-brood larvæ.	.....	Fourth....	Fourth.
Cover spray, second brood.	F.	9 to 10 weeks after A, just previous to time when second-brood larvæ begin to hatch.	Fourth....	Fifth.....	Fifth.
Do.....	G.	24 to 26 days after F, just previous to hatching of second-brood larvæ in large numbers.	.....	.....	Sixth.
Cover spray, second and third broods.	H.	34 to 36 days after F, just previous to hatching of second-brood larvæ in maximum numbers and for protection against third-brood larvæ.	Fifth.....	Sixth.....	.....
Do.....	I.	15 to 17 days after G, for late hatching second-brood larvæ and for protection against third-brood larvæ.	.....	.....	Seventh.

From the foregoing schedules it will be seen that the first or calyx treatment is given in each schedule and that it should be started when about 90 per cent of the petals have dropped, and should be finished before the calyces close. The object of this application is merely to fill the calyx or blossom end of the fruit so that the worms that attempt to enter by way of the calyx will be killed by the poison lodged therein. Any spray applied after the calyx cups have closed will have no value in checking calyx worms. This application should be very thorough, and, for the sake of speed, it is advisable to use a spray under a pressure of about 225 pounds.

Schedule I consists of four cover sprays, the first of which should be applied three to four weeks after the calyx application, just previous to the time when the first-brood larvæ begin to hatch. This application will serve to coat the young fruit and foliage with poison as a protection against the early hatching worms. The second cover spray for the first brood should be applied 15 to 17 days later, just before the first-brood larvæ hatch in maximum numbers. The first cover spray for the second brood should be made 9 to 10 weeks after the calyx treatment, just prior to the time when the second-brood larvæ begin

to hatch. The next and last application should be made 34 to 36 days later, in advance of the hatching of the second-brood larvæ in maximum numbers and for protection against the third-brood larvæ.

Schedule II is similar to schedule I except that five cover sprays are used instead of four, the additional application being made for the first-brood larvæ. The second cover spray should be applied 10 to 12 days after the previous treatment so as to cover the fruit just in advance of the hatching of the first-brood larvæ in large numbers. The next application should be made 10 to 12 days later as a means of protection against the late hatching first-brood larvæ.

Schedule III includes a total of seven applications, the first four being similar to those of schedule II. But in schedule III, three applications should be made for the second and third broods, the first of which should be applied 9 to 10 weeks after the calyx treatment, previous to the hatching of the second-brood larvæ. The next application should follow in 24 to 26 days, just before the hatching of the second-brood larvæ in large numbers and the last should be applied 15 to 17 days later, for late hatching second-brood larvæ and protection against worms of the third brood. .

AVOID PRESENCE OF SPRAY RESIDUE ON HARVESTED FRUIT.

Orchardists understand the importance of and will naturally give attention to the carrying out of any spraying schedule in such a manner as to obviate as completely as possible the presence of spray residue on fruit prepared for the market. Such residue is objectionable to consumers, and while there is little chance of injury resulting from its use, there is no necessity under average conditions to spray to an extent that results in much spray on the fruit at harvest time. A heavy coat of spray residue at harvest time is frequently due to an attempt on the part of the grower to protect his nearly ripened fruit from an abundance of late hatching worms. This condition would not be so common or serious if the proper action and same amount of endeavor were directed against the elimination of the first-brood worms.

During certain seasons of unusual worminess or with particularly susceptible varieties, seven treatments may not always give the desired results, but it is believed that in most instances seven thorough, well-timed applications will give as good results as can be economically obtained in the Grand Valley.

The foregoing schedules are based on the general average life history of the codling moth in the Grand Valley under normal climatic conditions. But if there should occur any unusual departure from the normal, a corresponding variation in the development of the insect is to be expected, and the schedule of applications should be modified accordingly. Small deviations, however, should not cause the fruit

grower to abandon his adopted schedule, since a matter of a few days one way or the other is not likely to affect the ultimate results to any marked extent.

Above all, the fruit grower should pay particular attention to spraying for the first-brood larvæ and make every effort to poison as many of these as possible. If all of the first-brood worms were killed there would be none of the second or third broods with which to contend. Upon inspection of their orchards early in the season, fruit growers sometimes conclude that there are so few worms present that it is unnecessary to make additional spray applications for the first brood. Unfortunately, it is not always realized that the presence of a comparatively few larvæ early in the season will often result in large second and third broods, which frequently will cause an enormous loss despite the most thorough subsequent spraying. The fruit grower should therefore bear in mind that during the early part of the season, while the fruit is small and the skin is not very waxy, it is easier to coat it thoroughly with poison and thus kill the worms than later in the year when the apples have grown larger and the skin has become smoother. Unless the fruit grower makes every effort to reduce to the minimum the number of first-brood larvæ, he will have small chance of success against the later broods. Neglect to spray with thoroughness and timeliness against the first brood of worms can never be economically or successfully overcome by sprays applied late in the season.

SPRAY MATERIALS.

Arsenate of lead at the rate of 1 pound of the powder or 2 pounds of the paste to 50 gallons of water is recommended as the most satisfactory poison for use against the codling moth. For convenience in handling and storing, the powdered product is preferable to the paste.

Although the experimental data did not always indicate that the addition of fish-oil soap to the arsenate of lead spray was of value, it is believed, nevertheless, that the use of soap, 2 pounds to 50 gallons, will generally increase the efficiency of the spray on account of the spreading qualities of the soap. Soap, however, should never be used with strongly alkaline water.

SPRAYING EQUIPMENT.

To spray the orchard as quickly as possible during the critical periods, it is recommended that a power sprayer of ample capacity and capable of supplying three leads of hose with a pressure of 225 to 250 pounds be used. In spraying large trees a spray tower, erected on top of the outfit, will enable the operator to cover the upper parts of the trees more thoroughly. A tank filler is almost a necessity and each sprayer should be provided with this device. It is also important

to have well-made hose of sufficient length and hose couplings and clamps that will stand the strain of the work without breaking or allowing the hose to be forced off during the spraying operations.

As previously stated, it is believed that the use of spray poles equipped with the whirlpool-disk type of nozzles will result in a larger percentage of clean fruit than if the short rod and Bordeaux nozzle or the spray gun are used. The last two methods of spraying, however, will save considerable time and it is therefore a question of the value of time against a somewhat greater quantity of fruit free from worms. The choice of method will depend upon availability and cost of labor, weather conditions, size of orchard, and number of spray machines, severity of infestation, variety of fruit, and other factors. Under some circumstances the grower may find it an advantage to use the spray gun for the calyx application and the first cover spray, changing to the poles and finer sprays for the later treatments when the fruit is larger and the skin is smoother, more waxy, and more difficult to coat with the spray liquid.

SUPPLEMENTAL CONTROL MEASURES.

BANDING.

Despite the most thorough spraying some first brood larvæ will escape the poison, and after completing their feeding period within the fruit will leave it and spin their cocoons on the tree trunk and later develop into moths which will in turn produce second-brood larvæ. As a means of catching these larvæ the banding method may be practiced. This consists of scraping the trunk to remove the loose bark, thus destroying most of the places where the larvæ hide, and then placing around the trunk a burlap band, folded into two or three thicknesses to a width of about 6 inches. These bands should be examined every 10 days from about the middle of June to August 31, and all of the larvæ and pupæ found beneath should be killed. A final examination should be made any time after the fruit is harvested. The banding method, if properly worked from year to year in conjunction with thorough spraying, will gradually reduce the number of individuals in the orchard so that a larger percentage of worm-free fruit will be obtained than with spraying alone.

CODLING-MOTH TRAP.

A codling-moth trap has been devised as a substitute for the banding method. This device will serve the same purpose as banding and will obviate the necessity of working the bands during the growing season when labor is usually much needed for other duties. While the spraying experiments do not indicate any pronounced benefit through the use of the codling-moth trap, it should be borne in mind that this device was used only one season and then only in a part of

each of the orchards; hence there was no chance to determine what cumulative effect it might have if used over a series of years and if applied to all of the trees in the orchard. Since we have no experimental data to indicate the cumulative value of the trap the writers are not in a position to make any recommendations, but for those who wish to give the trap a trial the following method of manufacture is suggested.

MANUFACTURE.

The materials needed for the manufacture of the codling-moth trap are as follows: Medium to heavy burlap, ordinary black-painted or japanned wire screen having 12 meshes to the inch, a folding machine such as that used by tanners to fold the edge of tin sheeting, and a crimping machine such as that used to reduce the end of stove pipe.

The burlap is cut into strips 6 inches wide and folded into three thicknesses by any convenient method. Wetting the burlap will make it fold more easily and remain better creased. To assist in this, however, it is well to roll the burlap up in flat rolls of any convenient size so that they can be easily handled in the field.

The wire screen is also cut into strips 6 inches wide and of any convenient length, depending on the length of the machine used to fold the edges. The edge of each strip should be folded at least once, preferably twice, using the folding machine mentioned above or any other convenient method. This fold should not be over three-eighths to one-half of an inch wide if folded once and not over one-fourth of an inch wide if folded twice. It is essential that the wire should be folded at least once and preferably twice, as the edges can then be crimped much better in the crimping machine and a more desirable bulge produced. Both edges of the strip are then run through the crimping machine, which should be set to make a fairly deep crimp without cutting the wire and about three-fourths to one inch from each edge. This crimp will aid greatly in giving, as stated above, a desirable bulge to the wire when it is applied to the tree, and further it will allow for the expansion of the tree trunk as it grows throughout the season. As the wire comes from the crimping machine it can well be rolled up into small rolls, which will greatly assist in keeping the crimp intact and also facilitate the manipulation of the wire in the field. If the crimping machine mentioned above can not be had, some other method, such as tucking the edges, must be adopted to give the desired bulge and to keep it away from the burlap on the tree.

APPLICATION.

The materials needed for the application of the codling-moth trap to the tree are as follows: A supply each of burlap and wire screen prepared as described above, a supply of slate nails about an inch or

more long, 10-ounce bill-posting tacks, tinner shears, a claw hammer, tar such as that used for roofing purposes (sometimes called "pitch tar"), a melting pot or a small pail conveniently arranged over a flame, and a small dauber.

The strip of folded burlap is then placed completely about the trunk of the tree to be trapped. It may be placed at any convenient height between the lowest limb and the ground, and an overlapping of an inch or two should be left to allow for the expansion of the tree. The loose bark should be scraped from the trunk, lower branches, and the crotches of each tree on which the codling-moth trap is applied in order to destroy as many places as possible where the codling-moth larva might spin its cocoon and there transform to the adult or moth stage. The burlap should be held in place by slate nails about an inch in length driven in at several points around the tree trunk so that the head projects not less than half an inch beyond the burlap, preferably three-fourths of an inch. This is essential in order to hold the wire safely away from the burlap at such a distance as will prevent the pupæ, just before the moths emerge, from wriggling up to or through the meshes of the wire and the moths from emerging on the outside of the trap.

With the burlap in place and the slate nails in their proper position, the wire screen, as prepared above, is ready to be tacked into place. Start at any convenient point and in any convenient direction around the tree by putting one tack in the corner on the lower edge of one end of the wire-screen strip, holding the strip so that the burlap band will be in the middle. Then place a tack in the corner on the upper edge, shoving down on this edge slightly, so as to spring the wire away about $1\frac{1}{2}$ inches or more from the tree at this point. Proceed around the tree trunk with the wire, holding it so that the burlap will be in the center all the way around and placing just enough of the 10-ounce bill-posting tacks along the edges of the wire to hold it snugly to the tree at all points, particularly where there are slight depressions or hollows which can not be sealed over with the tar, as outlined below.

Here care should be taken not to stretch the wire while it is being tacked to the tree, as this will pull out the crimp and make the formation of a desirable bulge rather difficult. Care should also be taken while the wire is being tacked into place to push the two edges together somewhat in order to increase the bulge already made by the crimping. This bulge should be large enough so that the middle of the strip will be approximately 1 inch from the burlap at every point. It is entirely possible to produce a bulge of over 2 inches, provided the wire is properly crimped and the edges are pushed together in the proper fashion. A little practice, however, will develop considerable skill along this line. An overlapping of

several inches should be left when the wire has been completely fastened around the trunk of the tree, and this overlapping should be stretched slightly over the wire beneath, so as to make a tight joint. If, as pointed out above, care is taken to produce a bulge sufficient to hold the wire well away from the burlap, to fit the wire snugly to the tree and make the overlapping tight, the codling-moth trap will remain in perfect operation throughout the season. It will then be practically impossible for the pupæ, just before the moths emerge, to work their way up to the wire, allowing the moths to emerge on the outside of the trap, a thing which is sure to happen when the wire is close to the burlap.

Care should be taken that there are no openings between the wire and the tree trunk through which moths may escape from the trap. These can be prevented by placing a thin coating of ordinary roof tar over the edges of the trap. This is a very practical and convenient method of making traps moth-tight. The tar can be conveniently melted in a small melting pot or pail held over a flame and can be applied best by means of a small stick with a bit of cloth on the end. Tar can not be applied easily with a brush. In applying the tar, roll the stick or the dauber toward the tree as it is passed along the edges of the trap. The tar need not be applied until shortly before the time the first moth of the first brood emerges.

MAINTENANCE.

When once attached to the tree as outlined above and carefully sealed with tar, the codling-moth trap should remain in perfect operation throughout the season and should require very little attention. In some cases an inspection the following spring to close up any holes which may have formed will be sufficient to put the trap in condition for another year.

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PROFESSIONAL PAPER

September 20, 1921

GARDEN FLEA-HOPPER IN ALFALFA AND ITS CONTROL.

By A. H. BEYER, *Scientific Assistant, Cereal and Forage Insect Investigations.*

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INTRODUCTION.

Little information has been recorded regarding the biology, habits, and control of *Halticus citri*, known as the garden flea-hopper. Dr. F. H. Chittenden was the first to attach to *Halticus citri* (Ashmead), then known as *Halticus uhleri* (Giard), the common name, chosen because of the insect's injuries to truck crops and its saltatory power.

In addition to other leguminous plants the insect attacks alfalfa, injuring the plant by sucking the juices, and in fields where heavy infestation occurs may cause the loss of 50 to 60 per cent of the crop. As little was known of the insect outside of its depredations on truck crops, observations and life-history studies on the garden flea-hopper on alfalfa were conducted during the years 1915, 1916, and part of 1917, at Columbia, S. C., and also a series of control experiments for the purpose of determining the most effective means of combating outbreaks of the pest. The bulletin, therefore, gives the results accomplished by means of a combination of field and laboratory experiments.

ORIGIN AND DISTRIBUTION.

The present known range of the garden flea-hopper covers a large portion of the United States (fig. 1). This insect belongs to the family Capsidae of the Heteroptera, is quite generally distributed throughout the eastern half of the United States, and in most instances has been reported as injurious to crops.

The garden flea-hopper is apparently American in origin. There are, however, two cases on record where it is reported as being de-

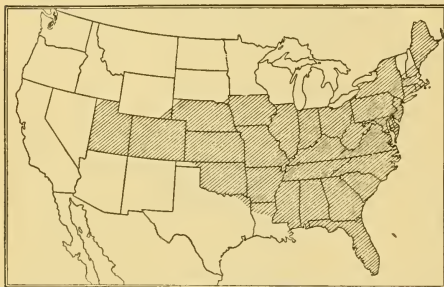


FIG. 1.—Map showing States where the garden flea-hopper (*Halticus citri*) has been found.

structive to crops outside of the United States, viz, Brazil and French Cochin China. In the latter region it seriously infested the peanut crop.¹

During the summer of 1916 the writer made numerous observations with a view of determining what effect altitude might have upon the dis-

tribution of this species. Sweepings made at the points mentioned below showed the presence of the adults and nymphs in the highest as well as the lowest altitudes where collections were made. The trip included visits during the month of August, 1916, to alfalfa and clover fields at Macon, Ga.; Gray, Ga.; Sylva, N. C.; Waynesville, N. C.; Asheville, N. C.; Statesville, N. C.; Columbia, S. C.; and Gainesville, Fla. The territory covering these points included a range of altitude from 180 feet to 2,700 feet. Gray, Ga., which has an altitude of 500 feet, was the center of the 1915 outbreak.

¹ The following notes on the garden flea-hopper (*Halticus citri*) and list of localities have been compiled from field studies in the United States and from specimens contained in the collections of the U. S. National Museum: Orange Springs, Fla., 1887 (W. H. Ashmead); Riley Co., Kans., Sept. 10, 1892 (C. L. Marlatt); Washington, D. C., June 22, 1897; Columbia, Mo., no date (C. V. Riley); Berkeley Springs, W. Va. (P. R. Uhler); Auburn, Ala., no date (P. R. Uhler); Experiment Station, Manhattan, Kans., 1889 (E. A. Smith); Experiment Station, Hartford, Conn., Sept., 1914 (W. E. Britton); Stillwater, Okla., Oct., 1912 (C. E. Sanborn); Topeka, Kans., Aug. 30, 1917 (E. A. Popenoe); Chicago, Ill., July 13, 1908 (J. J. Davis); Clemson College, S. C., July 16, 1909 (G. G. Ainslie); Nashville, Tenn., Sept. 5, 1910 (G. G. Ainslie); Experiment Station, Utah, 1893 (P. R. Uhler); Winchester, Va., July 13, 1913 (E. B. Blakeslee); Washington, D. C., 1917 (F. H. Chittenden); Gray, Ga., 1915 (R. J. Stewart); Gray, Ga., May 26, 1915 (A. H. Beyer); Macon, Ga., May 27, 1915 (A. H. Beyer); Lafayette, Ind., Aug. 11, 1916 (J. J. Davis); Atlanta, Ga., Aug. 25, 1916 (A. H. Beyer); Statesville, N. C., Aug. 31, 1916, Waynesville, N. C., Aug. 27, 1916 (A. H. Beyer); Asheville, N. C., Aug. 28, 1916 (A. H. Beyer); Charlotte, N. C., Aug. 31, 1916 (A. H. Beyer); Hagerstown, Md., Sept. 12, 1912 (H. L. Parker); Columbia, S. C., Oct. 5, 1915 (A. H. Beyer); Ithaca, N. Y., Oct., 1915 (H. H. Knight); Boston, Mass., Sept., 1915 (H. H. Knight); Springfield, Mo., July, 1915 (H. H. Knight); Quincy, Fla., May 23, 1916 (F. H. McDonough); Lakeland, Fla., Dec. 16, 1916 (A. H. Beyer); Fulton Co., N. Y., Aug., 1911 (C. P. Alexander); Indianapolis, Ind., Aug. 25, 1916 (H. F. Dietz); Gainesville, Fla., Feb. 28, 1917 (A. H. Beyer); Charleston, Mo., May 26, 1916 (E. H. Gibson); Hot Springs, Ark., May, 1916 (E. H. Gibson); Chapel Hill, N. C., Sept. 21, 1915 (P. Luginbill).

P. R. Uhler (5)² recorded the garden flea-hopper as having been found at the experiment station at Logan, Utah, which point has an approximate altitude of 4,700 feet above sea level.

SYNONYMY.

The garden flea-hopper was first named and described by Ashmead (1) as *Rhinocloa citri*. E. A. Popenoe (2) in 1890 called it "*Halticus minutus* Uhler MS." During the same year Giard (3) re-named the species *uhleri*, since there was already a *Halticus minutus* Reuter. Distant (4, p. 430) in 1893 redescribed the species as *Calocoris canus*, not recognizing its true affinities.

Reuter (12) in 1909 first pointed out that *Rhinocloa citri* Ashmead and *Halticus uhleri* Giard were the same, but he left the species under the latter name until 1914, when H. G. Barber (15) used the combination "*Halticus citri* (Ashm.)" in print.

The synonymy, therefore, is as follows:

***Halticus citri* (Ashmead) Barber.**

Rhinocloa citri Ashmead (1).

Halticus minutus (Uhler MS) Popenoe (2).

Halticus uhleri Giard (3).

Calocoris canus Distant (4).

Halticus citri Barber (15).

HISTORY OF THE SPECIES AND ITS INJURIES.

Halticus citri seems first to have received economic mention in 1887, by W. H. Ashmead (1), who found it on orange trees in Florida.

In 1892 A. Giard (3) recorded it as being destructive to peanut and rice crops of French Cochinchina and Singapore, Straits Settlements.

This species, with *Agalliastes bractatus* Say, was reported from Kansas in 1890 (2) as follows:

We have the past season observed two species of Capsidæ, or plant-bugs, living in great numbers on the underside of the leaves of the garden bean, puncturing the tissues and sucking the sap, and by these punctures causing the death of the tissues in small, irregular patches, that appear upon the upper surface of the leaf as white spots.

It was found by J. B. Smith (6, p. 133) in New Jersey during 1900 injuring truck crops at the following places: New Brunswick, Jamesburg, Swedesboro, Madison, Camden County, and Vineland.

In 1900 F. M. Webster (7) reported it from Wooster, Ohio. F. H. Chittenden (8) states:

In May and June, 1900, this insect was observed in some numbers on beans in different localities, and some leaves were found to have been killed by its attacks. Beets and cabbage were also affected, but injury was less noticeable to these crops. In 1901 the writer noticed severe injury to ornamental morning-glory in the city of Washington.

² Reference is made by number (italic) to "Literature cited," p. 27.

W. E. Britton (9) of Connecticut, during September, 1904, received specimens of the insect from Southport, Conn., with the statement that much injury was being done by it to smilax growing under glass. Injury to beans, beets, red clover, cowpeas, potatoes, chrysanthemums, morning-glories, eggplant, cabbages, and pumpkins also occurred at that time.

In 1907 F. H. Chittenden (10, p. 118) reported that the insect "lives in great numbers on the leaves, puncturing them so as to cause the death of the tissues in small irregular white patches. In its short-winged form it resembles the black flea-beetles, which affect potato, alike in appearance, in the nature of its work, and in its saltatory power. Other food plants include potato, pumpkin, cabbage, ornamental plants, clover, and many weeds."

In 1907 F. M. Webster recorded *H. uhleri* as destructive to alfalfa over small areas at Topeka, Kans.

In the Yearbook of 1908 Dr. Chittenden (11) gives the following account of *H. citri*:

The garden flea-hopper (*Halticus uhleri* Giard) was more or less injurious to cucumbers, squash, and beans in New Jersey; to beans in the District of Columbia, and to lettuce and sweet potato in the trucking region of Norfolk, Va.

C. E. Sanborn (14) found the species destructive to alfalfa in Oklahoma in 1912. During the same year J. J. Davis (13) gives the following account of *Halticus citri*:

This flea-hopper did much damage to smilax in several greenhouses around Chicago in 1908 . . . and just outside of the house the weeds were much infested with it—the latter fact probably accounting for its presence indoors. Early in the spring of 1909 the adults—fully winged males and females as well as the short-winged form—were found abundant in one greenhouse at a date which would preclude any possibility of their having developed out-of-doors that spring; and they did not develop inside the greenhouses from eggs deposited the fall before, as the houses had been examined during the winter and not an active "hopper" found. It was also observed that the individuals became adult in the fall, as cold weather set in. From these observations it appears that the adults hibernate in greenhouses or out-of-doors and become active in the spring, when they deposit their eggs for that season's generation—instead of doing it in the fall before, as has heretofore been supposed.

Following are from the notes of Mr. G. G. Ainslie, of the Bureau of Entomology:

Clemson College, S. C., July 16, 1909: The alfalfa is conspicuously whitened by the adults and larvæ of this bug which have come there from the adjoining peas. The habitats of the insect seem to be the same on alfalfa as peas. The adults are found on both sides of the leaves but mainly the lower, while the larvæ are confined to the lower side.

Nashville, Tenn., September 5, 1910: Found a field of alfalfa badly whitened by the attacks of this species. The plants looked sickly from the work of these bugs.

July 13, 1913, Mr. E. B. Blakeslee of Winchester, Va., reported to Prof. A. L. Quaintance of the Bureau of Entomology the occurrence of enormous numbers of *H. citri* in alfalfa fields, both in the adult and

nymphal stages. Mr. J. R. Stewart, of Gray, Ga., under the date of May 9, 1915, reported severe injury by the garden flea-hopper to a field of alfalfa that had yielded fine crops for two years.

Mr. E. H. Gibson on May 26, 1916, reported it as being injurious to alfalfa at Charleston, Mo.

RECENT INJURIES.

During the year 1915 serious attacks by *Halticus citri* on cereal and forage crops in the South Atlantic States, and especially in Georgia,



FIG. 2.—Alfalfa showing the effect of injury by the garden flea-hopper on the leaves.

directed the attention of the Bureau of Entomology to the need of investigational work with respect to this insect. The late Prof. F. M. Webster, entomologist in charge of cereal and forage insect investigations, immediately instituted researches for the purpose of determining suitable control measures.

The writer began his investigations at Gray, Ga., May 26, 1915. In walking through the alfalfa fields at this place infestation by the garden flea-hopper was found exceedingly abundant, the insect being present in all stages of its life cycle; the distribution of the pest in

each field was found to be quite uniform excepting along the fences, where the plants were most seriously affected, leaves being discolored and dropping off, and the plants dying in frequent instances.

It was observed that the injury caused to alfalfa by *Halticus citri* very closely resembled that of the red spider (*Tetranychus bimaculatus* Harv.).

All the cereal and forage and truck crops, wild mulberry trees, peach trees, and a large number of weeds, including the briar and



FIG. 3.—At the right, normal healthy leaves of red clover. At the center and left, leaves seriously affected by the garden flea-hopper.

species of the mint family, were found infested with this insect. More noticeable damage, however, was shown by alfalfa, cowpeas, and clover than by other growing crops.

DAMAGE TO ALFALFA.

The injury which is inflicted on alfalfa and other plants is caused by both adults and nymphs. Damage is done by means of their sharp pointed mouth-parts which are inserted into the plant tissues. The short chitinized beak is thrust through the surface of the leaf or its

petiole and sap is extracted, giving the leaves a bleached appearance and often killing them. In extreme cases the stems of the plants are attacked in like manner. The greatest amount of damage results from the loss of plant sap or juices. The leaves die and in many instances drop from the stems and cause the infested plants to appear as bunches of stubble. (See figs. 2 to 6.)

The loss to the crop has been estimated by the writer as high as 50 to 60 per cent in several severely infested fields where the alfalfa had been cut and the cured hay removed. The damage is quite noticeable



FIG. 4.—White clover showing the effect of injury on the leaves by the garden flea-hopper.

in the field, since the plants have not the green color and freshness characteristic of plants that are uninjured,* and have become fibrous, contrasting with other plants of luxuriant growth and thrifty condition. The extraction of the plant juices checks the growth of the plant, causing it to shrivel up and in a number of instances to die. After the crop has been cut and the hay removed from the field an inspection of the alfalfa field shows that a large number of the leaves have fallen from the plants and been left lying on the ground, causing a loss of much of the food

value of the hay. This is due in large measure to the injury resulting from the feeding of the garden flea-hopper upon the petioles, leaves, and tender stems.

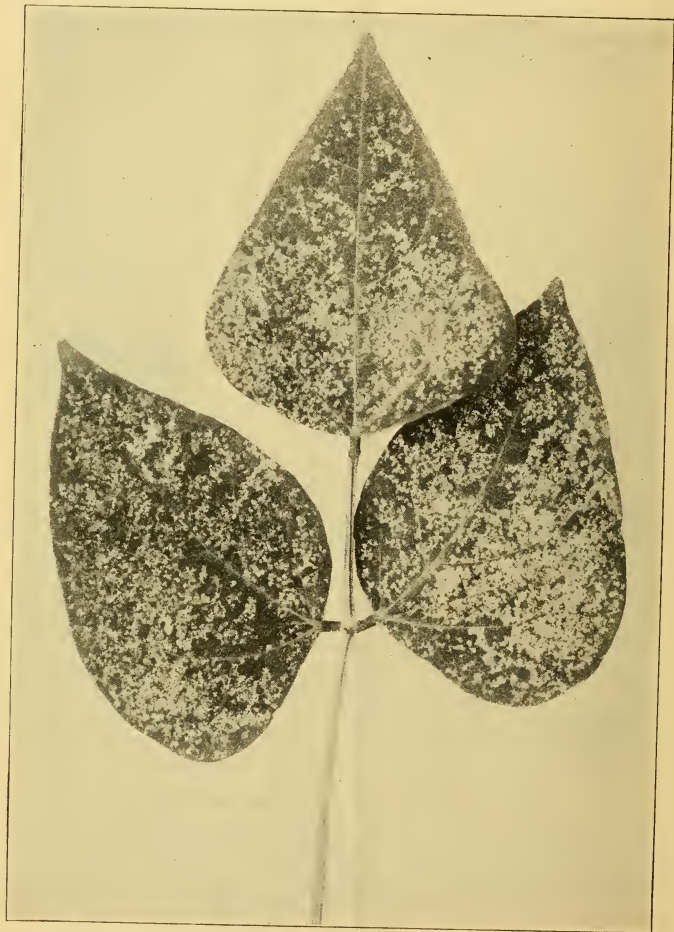


FIG. 5.—Cowpeas showing the effect of injury by the garden flea-hopper on the leaves.

HOST PLANTS.

Throughout the South Atlantic States the species was found prevalent on alfalfa, the clovers, cowpeas, and some of the common

weeds. All common garden truck was also found to be among the favorite host plants with the possible exception of the red pepper plant which showed very slight attack or injury. It was found on

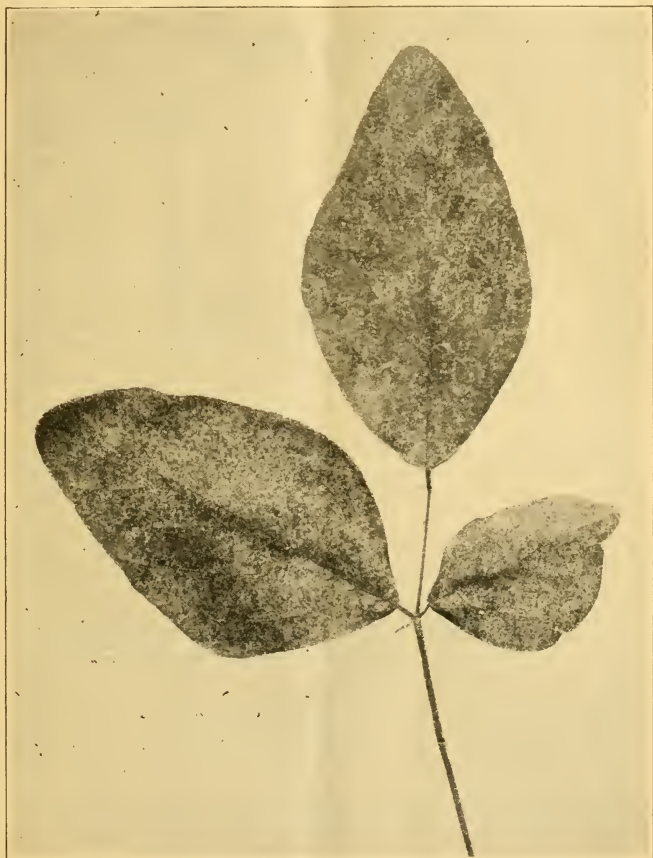


FIG. 6.—Beggar-weed (*Meibomia tortuosa*) showing the effect of feeding of the garden flea-hopper upon the leaves.

plants in greenhouses the year round, and on the out-of-door flowering plants it was especially noticeable in the early spring and late fall, although also common throughout the summer.

Tables I, II, and III were prepared after a close examination of the most seriously infested host plants collected from the fields in which outbreaks occurred, and show that alfalfa is most frequented by *Halticus citri* for egg laying.

TABLE I.—*Infestation in alfalfa by Halticus citri, showing the number of eggs in each leaf and where deposited.*

Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.	Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.
1.....	3	1	4	27.....	3	0	3
2.....	11	0	11	28.....	2	0	2
3.....	12	7	19	29.....	3	0	3
4.....	5	1	6	30.....	16	2	18
5.....	2	1	3	31.....	30	0	30
6.....	1	1	2	32.....	53	0	53
7.....	7	0	7	33.....	10	7	17
8.....	3	0	3	34.....	31	0	31
9.....	15	0	15	35.....	6	0	6
10.....	4	0	4	36.....	23	0	23
11.....	5	0	5	37.....	15	1	16
12.....	1	0	1	38.....	23	15	38
13.....	28	1	29	39.....	2	0	2
14.....	4	0	4	40.....	3	0	3
15.....	5	10	15	41.....	5	0	5
16.....	0	0	0	42.....	2	1	3
17.....	1	0	1	43.....	2	0	2
18.....	2	5	7	44.....	3	0	3
19.....	10	1	11	45.....	5	0	5
20.....	2	0	2	46.....	3	0	3
21.....	12	4	14	47.....	7	1	8
22.....	2	2	4	48.....	1	1	2
23.....	1	0	1	49.....	20	1	21
24.....	6	1	7	50.....	9	0	9
25.....	8	1	9				
26.....	1	0	1	Total..	428	65	493

TABLE II.—*Infestation in clover by Halticus citri, showing the number of eggs in leaf and where deposited.*

Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.	Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.
1.....	2	0	2	27.....	0	0	0
2.....	0	0	0	28.....	1	0	1
3.....	3	1	4	29.....	8	6	14
4.....	7	3	10	30.....	5	1	6
5.....	11	1	12	31.....	14	0	14
6.....	9	0	9	32.....	9	3	12
7.....	14	2	16	33.....	2	4	6
8.....	2	0	2	34.....	13	2	15
9.....	0	0	0	35.....	1	0	1
10.....	10	0	10	36.....	0	3	3
11.....	1	0	1	37.....	0	1	1
12.....	4	0	4	38.....	6	0	6
13.....	0	0	0	39.....	4	0	4
14.....	1	1	2	40.....	2	4	6
15.....	3	0	3	41.....	1	0	1
16.....	5	0	5	42.....	10	1	11
17.....	8	2	10	43.....	0	0	0
18.....	0	1	1	44.....	1	0	1
19.....	2	0	2	45.....	5	0	5
20.....	4	0	4	46.....	2	0	2
21.....	1	0	1	47.....	7	1	8
22.....	6	2	8	48.....	4	0	4
23.....	0	0	0	49.....	9	2	11
24.....	1	0	1	50.....	3	0	3
25.....	10	3	13				
26.....	11	1	12	Total...	222	45	267

TABLE III.—*Infestation in cowpeas by Halticus citri, showing the number of eggs in the leaf and where deposited.*

Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.	Leaf No.	Eggs deposited in upper surface.	Eggs deposited in lower surface.	Total number of eggs deposited.
1.....	4	1	5	27.....	9	0	9
2.....	0	0	0	28.....	3	6	9
3.....	1	0	1	29.....	1	0	1
4.....	2	0	2	30.....	2	0	2
5.....	0	0	0	31.....	0	0	0
6.....	6	0	6	32.....	6	0	6
7.....	1	6	7	33.....	1	0	1
8.....	0	0	0	34.....	4	1	5
9.....	6	2	8	35.....	1	0	1
10.....	9	0	9	36.....	11	2	13
11.....	10	2	12	37.....	0	3	3
12.....	4	0	4	38.....	2	0	2
13.....	1	0	1	39.....	7	0	7
14.....	2	0	2	40.....	3	1	4
15.....	5	0	5	41.....	2	0	2
16.....	0	0	0	42.....	0	0	0
17.....	8	1	9	43.....	1	0	1
18.....	1	4	5	44.....	0	0	0
19.....	0	8	8	45.....	4	1	5
20.....	6	1	7	46.....	2	0	2
21.....	4	0	4	47.....	1	0	1
22.....	6	0	6	48.....	3	0	3
23.....	1	0	1	49.....	2	1	2
24.....	12	2	14	50.....	1	0	1
25.....	7	0	7				
26.....	2	4	6	Total...	154	46	210

In the field observations and laboratory studies it was found that *Halticus citri* prevails on a wide range of species of host plants. The following is a list of the host plants, as noted by the writer, together with those recorded in the literature:

Alfalfa (*Medicago sativa*), red clover (*Trifolium pratense*), cowpeas (*Vigna sinensis*), ragweed (*Ambrosia artemisiacifolia*), hollyhock (*Althaea rosea*), ground cherry (*Physalis pubescens*), sorghum (*Andropogon sorghum*), prickly lettuce (*Lactuca scariola*), burdock (*Arctium lappa*), thistle (*Cnicus arvensis*), crab-grass (*Syntherisma sanguinale*), Kentucky bluegrass (*Poa pratensis*), oats (*Avena sativa*), rye (*Secale cereale*), wheat (*Triticum vulgare*), corn (*Zea mays*), rape (*Brassica napus*), barley (*Hordeum vulgare*), Jerusalem artichoke (*Helianthus tuberosus*), Johnson grass (*Andropogon halepensis*), celery (*Apium graveolens*), wild mulberry (*Morus rubra*), bur clover (*Medicago arabica*), sweet clover (*Melilotus alba*), wild morning-glory (*Convolvulus arvensis*), hackberry (*Celtis occidentalis*), cocklebur (*Xanthium* sp.), eggplant (*Solanum melongena*), Irish potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), peach (*Amygdalus persica*), cucumber (*Cucumis* sp.), tomato (*Lycopersicon lycopersicon*), tobacco (*Nicotiana tabacum*), bean (*Phaseolus* sp.), May-pops (*Passiflora incarnata*), marigold (*Calendula officinalis*), verbena (*Verbena incisa*), cotton (*Gossypium hirsutum*), beggar-weed (*Meibomia tortuosa*), white clover (*Trifolium carolinianum*).

DESCRIPTION.

ADULT.

On first sight the brachypterous female adult of this species (fig. 7) is likely to be confused with that of a flea-beetle, since both are saltatorial and resemble each other in color and general appearance, even though they represent two different orders.

The male (fig. 8) has the normal form of the Hemiptera, while the brachypterous female may easily be taken for another species. The macropterous female (fig. 9) resembles the male, having long wings but is somewhat larger than the male.

H. H. Knight, of the department of entomology, Cornell University, Ithaca, N. Y., has kindly drafted the following redescription of the adult, from specimens furnished by the writer from Columbia, S. C.

Slightly smaller and less shining than *apterus* L.; in addition to the vestiture of very fine pale pubescence, having on the dorsum deciduous tomentose patches which give silvery to greenish reflections as in *intermedius* Uhler.



FIG. 7.—*Halticus citri*: Brachypterous female. Greatly enlarged.

MALE (MACROPTEROUS).

Length 2.1 mm. (1.9 to 2.1 mm.), width 0.74 mm.; slightly smaller and more slender than the female.

Head.—Length 0.22 mm., width across eyes 0.56 mm., vertex 0.31 mm. Nearly vertical, front prominent, more or less sulcate at the base of the tylus; black, shining; carina formed by a sharp basal margin of the head. Rostrium reaching to the posterior margin of the middle coxæ; first two segments black, the third and all but the apex of the fourth pale.

Antennæ.—Long and slender, reaching beyond the tip of the membrane; segment I, length 0.25 mm., pale, sometimes darkened at the apex, two or three prominent bristles just before the tip; II, 1.05 mm., black, linear, and slender; III, 0.83 mm., fuscous to black, usually pale at the base, more slender than the second; IV, 0.54 mm., fuscous, very slender.

Pronotum.—Length 0.40 mm., width at base 0.74 mm., collar and calli not apparent; black, moderately shining, the disk having patches of deciduous tomentose pubescence as on the hemelytra. Scutellum, sternum, and pleuræ black, moderately shining.

Hemelytra.—Sides nearly parallel; black, the clavus and corium having patches of deciduous tomentose pubescence, the patches arranged in more or less definite rows; cuneus black, the apex pale yellowish. Membrane pale, tinged with fuscous, one cell apparent but not distinct.

Legs.—Long and slender, the hind femora saltatorial, coxæ black, front and middle femora pale yellow, the hind pair black with the apex pale; tibiæ pale yellow, the hind pair fuscous near the base; tarsi pale yellowish, the tips fuscous, claws black.

Venter.—Black, moderately shining, genital claspers small but distinctive of the species.

FEMALE (MACROPTEROUS).

Length 2.17 mm., width 0.95 mm., very similar to the male but more robust and having the second antennal segment and the femora differently colored.

Head.—Length 0.25 mm., width across eyes 0.57 mm., vertex 0.31 mm.: not differing from the male.

Antennæ.—Segment I, length 0.22 mm., fuscous to blackish, paler at the base; II, 0.98 mm., pale with the basal and apical one-fourth blackish; III, 0.77 mm., fuscous, pale toward the base; IV, 0.48 mm., fuscous.

EGG.

Fig. 10.

Egg cylindrical, roundly pointed at caudal end, broadly truncate at cephalic end. One side decidedly convex, opposite side slightly concave. Chorion smooth, lustrous, pearly white, semitransparent, free from sculpture, except surface of truncate end, which is roughly shagreened. Truncate end apparently with a collar, below which the egg is slightly constricted, end ellipsoidal in outline. Dimensions, long diameter, 0.21 mm., short diameter, 0.10 mm. Length of egg, outer angle 0.71 mm., length of inner angle, 0.56 mm. Diameter at widest point, 0.20 mm.

NYMPH.

Figs. 11-15.

The nymph resembles the adult in general outline and structure but differs in color, and has, in the place of wings such as the adults

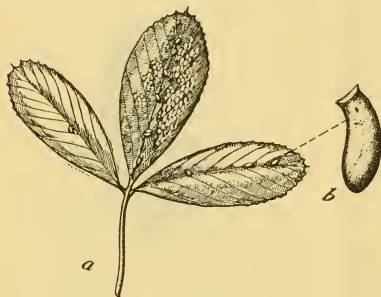


FIG. 10.—*Halticus citri*: a, Eggs in alfalfa leaf; b, egg greatly enlarged.

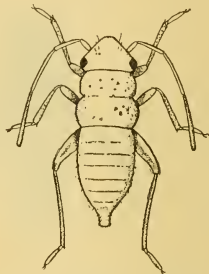


FIG. 11.—*Halticus citri*: First nymphal instar. Greatly enlarged.

have, dark-colored wing pads, these being most pronounced in the fifth stage. In the first nymphal instar the body is less robust and of a pale clay-yellow color at hatching which turns to pale green after feeding. During the period from the second to the fifth instars, inclusive, the thorax and abdomen increase in size laterally. The body gradually becomes more robust, and at the fifth instar it has assumed almost the shape and form of the adult. The color of the body varies from a light to a dark green.

The period of time consumed in the development of the nymph ranges from 10 to 18 days, or an average of 14 days, as shown in Table V.

FIRST INSTAR.

Fig. 11

Length 0.70 mm., width 0.19 mm. (average of 6 specimens). Number of body joints 13. Segments of abdomen 10. Head, thorax, abdomen, and all appendages pale clay color. Head as wide as body, as long as wide. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, carmine in color. Beak 0.21 mm. long; three joints, dark at apex. Antennæ tubular; composed of four joints, first slightly swollen, length 0.08 mm., second 0.15 mm., third 0.20 mm., fourth 0.25 mm.; total length 0.68 mm.

October, 1915, at Columbia, S. C.

Date of egg deposit.	Date of molt.	Length of stage V.	Total length of nymphal period.		Mean average temperature.
			Sex.	Period.	
		Days. hours.		Days. hours.	° F.
June 18.....	June a. m.	5 0	Male.....	11 19	76.6
Do.....	Do a. m.	4 0	Female.....	17 19	78.7
Do.....	Do p. m.	1 5	do.....	15 0	77.4
Do.....	June a. m.	4 0	Male.....	17 0	78.1
Do.....	Do a. m.	3 0	Female.....	14 0	77.4
Do.....	Do a. m.	3 0	Male.....	14 0	77.4
Do.....	Do a. m.	3 0	Female.....	14 0	77.4
Do.....	Do p. m.	3 0	Male.....	14 5	77.4
Do.....	Do a. m.	2 19	Female.....	15 0	77.8
Do.....	Do a. m.	3 0	do.....	14 0	77.4
Do.....	Do a. m.	3 19	Male.....	15 0	77.8
Do.....	Do a. m.	3 0	Female.....	14 0	77.4
Do.....	Do a. m.	4 19	Male.....	14 0	77.4
Do.....	Do a. m.	4 19	do.....	14 0	77.4
Do.....	Do p. m.	3 0	Female.....	12 5	77
Do.....	Do a. m.	4 0	do.....	16 0	78.1
Do.....	Do a. m.	1 0	Male.....	13 0	77.2
Do.....	Do a. m.	5 0	do.....	15 0	77.8
Do.....	Do a. m.	4 0	do.....	14 0	77.4
Do.....	Do a. m.	4 0	do.....	16 0	78.1
Do.....	Do a. m.	4 0	do.....	13 14	77.2
Do.....	Do a. m.	5 0	do.....	18 0	77.8
Average.....		3.6 0		14.1 0	77.66
July 21.....	July a. m.	3 0	Female.....	10 0	79
July 30.....	Aug a. m.	3 0	do.....	10 19	80
Do.....	Do a. m.	3 0	do.....	11 0	80
Do.....	Do a. m.	2 19	Male.....	10 0	80
Do.....	Do p. m.	2 5	Female.....	10 5	80
Do.....	Do a. m.	2 19	Male.....	11 0	80
Do.....	Do a. m.	2 0	do.....	10 5	80
Do.....	Do p. m.	2 19	do.....	11 0	80
Do.....	Do a. m.	2 19	Female.....	10 0	80
Do.....	Do a. m.	4 5	Male.....	11 5	80
July 31.....	Aug 10 a. m.	3 1	do.....	13 1	80
Aug. 1.....	Aug 2 p. m.	3 5	do.....	10 5	80
Do.....	Do a. m.	2 0	do.....	10 0	80
Do.....	Do a. m.	4 0	do.....	12 0	80
Do.....	Do a. m.	3 19	do.....	11 0	80
Aug. 2.....	Aug a. m.	3 17	Female.....	13 0	80
Do.....	Do a. m.	3 0	Male.....	13 0	80
Aug. 3.....	Aug 2 p. m.	3 0	Female.....	11 5	80
Aug. 4.....	Aug 10 a. m.	2 1	do.....	12 1	80
Do.....	Do p. m.	3 0	do.....	11 5	80
Aug. 5.....	Aug a. m.	3 0	Male.....	11 0	80
Do.....	Do p. m.	3 0	do.....	11 0	80
Aug. 6.....	Aug a. m.	4 19	do.....	11 19	80
Do.....	Aug a. m.	3 0	Female.....	12 0	80
Average.....		3.04 0		12 0	79.95
Oct. 2.....	Oct. a. m.	5 0	Male.....	16 0	71
Oct. 3.....	Do a. m.	4 0	Female.....	14 0	71
Oct. 2.....	Do a. m.	5 0	Male.....	16 0	71
Oct. 3.....	Do a. m.	5 0	do.....	16 0	71
Oct. 2.....	Dead.....				
Oct. 3.....	Do a. m.	5 0	Female.....	17 0	71
Average.....		4.8 0		15.8 0	71

TABLE V.—Number of instars, their length, and length of nymphal life of *Halticus citri* during the months of June, July, August, and October, 1915, at Columbia, S. C.

Date of egg deposit.	Date of hatching of egg.	Date of first molt.	Length of stage I.	Date of second molt.	Length of stage II.	Date of third molt.	Length of stage III.	Date of fourth molt.	Length of stage IV.	Date of fifth molt.	Length of stage V.	Total length of nymphal period.		Mean average temperature.
												Sex.	Period.	
			Days. hours.		Days. hours.		Days. hours.		Days. hours.		Days. hours.		Days. hours.	* F.
June 18.	June 26, 2 p. m.	June 28, 2 p. m.	3 0	June 29, 2 p. m.	3 0	June 30, 2 p. m.	3 0	July 2, 9 a. m.	3 0	July 7, 9 a. m.	3 0	Male.	14 0	76.6
Do.	do.	July 1, 2 p. m.	5 0	July 1, 9 a. m.	3 19	July 8, 9 a. m.	4 0	July 9, 9 a. m.	1 0	July 15, 9 a. m.	4 0	Female.	17 19	78.7
Do.	do.	June 28, 2 p. m.	2 0	July 2, 2 p. m.	4 0	July 3, 9 a. m.	3 19	July 4, 9 a. m.	6 0	July 10, 2 p. m.	1 5	do.	15 0	77.4
Do.	do.	do.	2 0	July 1, 9 a. m.	2 19	July 2, 9 a. m.	3 0	July 3, 9 a. m.	4 0	July 12, 9 a. m.	2 0	Male.	14 0	78.4
Do.	June 29, 9 a. m.	do.	3 5	July 2, 9 a. m.	2 19	July 3, 9 a. m.	2 0	July 7, 9 a. m.	3 0	July 10, 9 a. m.	3 0	Female.	11 0	77.4
Do.	do.	do.	3 5	July 3, 9 a. m.	3 19	July 5, 9 a. m.	2 0	do.	2 0	do.	3 0	Male.	13 0	77.4
Do.	do.	do.	3 5	July 3, 9 a. m.	3 19	July 5, 9 a. m.	2 0	do.	2 0	do.	3 0	Female.	14 0	77.4
Do.	do.	do.	3 5	July 3, 9 a. m.	3 19	July 5, 9 a. m.	2 0	do.	2 0	do.	3 0	Male.	14 5	77.4
Do.	do.	do.	3 5	July 2, 2 a. m.	3 0	do.	3 0	July 8, 2 p. m.	3 0	July 11, 9 a. m.	2 19	Female.	15 0	77.4
Do.	do.	do.	2 5	June 30, 2 p. m.	3 19	July 1, 2 p. m.	2 0	July 2, 2 p. m.	2 19	July 10, 9 a. m.	3 0	Male.	11 0	77.4
Do.	do.	do.	3 5	July 1, 2 p. m.	2 0	do.	3 0	July 7, 2 p. m.	3 0	July 11, 9 a. m.	3 19	Male.	15 0	77.4
Do.	do.	do.	3 5	July 2, 9 a. m.	2 19	July 5, 9 a. m.	3 0	July 7, 9 a. m.	2 0	July 10, 9 a. m.	3 0	Female.	14 0	77.4
Do.	do.	do.	2 5	June 30, 2 p. m.	2 0	July 2, 2 p. m.	2 0	July 5, 2 p. m.	3 0	do.	4 19	Male.	15 0	77.4
Do.	do.	June 28, 2 p. m.	2 5	do.	2 0	do.	2 0	do.	3 0	do.	4 19	do.	13 0	77.4
Do.	do.	do.	2 5	July 2, 2 p. m.	4 0	July 3, 2 p. m.	1 0	do.	2 0	July 8, 2 p. m.	3 0	Female.	12 5	77.4
Do.	do.	do.	2 5	June 30, 2 p. m.	2 0	July 2, 9 a. m.	2 19	July 3, 9 a. m.	6 0	July 12, 9 a. m.	3 0	do.	18 0	78.1
Do.	do.	do.	2 5	July 1, 2 p. m.	3 0	July 2, 2 p. m.	1 0	July 5, 9 a. m.	2 19	July 9, 9 a. m.	4 0	Male.	13 0	77.2
Do.	do.	do.	2 5	June 30, 2 p. m.	2 5	July 3, 2 p. m.	3 0	July 6, 9 a. m.	2 19	July 11, 9 a. m.	5 0	do.	15 0	77.8
Do.	do.	do.	2 0	do.	2 5	July 2, 2 p. m.	2 0	do.	3 19	July 10, 9 a. m.	4 0	do.	13 0	77.4
Do.	do.	do.	2 0	July 1, 2 p. m.	2 5	July 4, 2 p. m.	3 0	July 8, 9 a. m.	3 19	July 12, 9 a. m.	4 0	do.	16 0	78.1
Do.	do.	June 28, 9 a. m.	3 0	June 30, 2 p. m.	1 19	July 2, 9 a. m.	1 19	July 5, 9 a. m.	3 0	July 9, 9 a. m.	4 0	do.	13 14	77.2
Do.	do.	June 29, 9 a. m.	3 0	July 1, 2 p. m.	2 5	July 5, 9 a. m.	3 19	July 9, 9 a. m.	4 0	July 11, 9 a. m.	5 0	do.	18 0	77.8
Average.			2.77 0		2.68 0		2.27 0		3 0		3.6 0		11.1 0	77.66
July 21.	July 30, 9 a. m.	Aug. 1, 9 a. m.	1 0	Aug. 3, 9 a. m.	2 0	Aug. 5, 9 a. m.	2 0	Aug. 7, 9 a. m.	2 0	Aug. 10, 9 a. m.	3 0	Female.	10 0	79
July 30.	Aug. 7, 9 a. m.	Aug. 10, 9 a. m.	3 0	Aug. 11, 2 p. m.	1 0	Aug. 13, 2 p. m.	2 0	Aug. 15, 9 a. m.	1 19	Aug. 18, 9 a. m.	3 0	do.	10 19	80
Do.	do.	do.	3 0	Aug. 12, 9 a. m.	2 0	do.	1 5	do.	1 19	do.	3 0	do.	10 0	80
Do.	do.	do.	3 0	Aug. 11, 2 p. m.	2 0	do.	2 0	Aug. 14, 2 p. m.	2 0	Aug. 17, 9 a. m.	3 19	Male.	10 0	80
Do.	do.	do.	3 0	Aug. 13, 9 a. m.	1 0	do.	2 0	Aug. 15, 9 a. m.	2 0	Aug. 17, 2 p. m.	2 5	Female.	10 5	80
Do.	do.	do.	3 0	do.	2 0	do.	2 0	Aug. 15, 2 p. m.	2 5	Aug. 18, 9 a. m.	2 19	Male.	11 0	80
Do.	do.	do.	3 0	do.	2 0	do.	2 0	Aug. 17, 2 p. m.	2 5	Aug. 17, 2 p. m.	2 19	do.	11 0	80
Do.	do.	Aug. 10, 9 a. m.	3 0	do.	1 0	do.	2 0	do.	2 5	Aug. 18, 9 a. m.	2 19	do.	11 0	80
Do.	do.	Aug. 9, 9 a. m.	2 0	do.	2 0	Aug. 12, 2 p. m.	1 5	Aug. 14, 2 p. m.	2 0	Aug. 17, 9 a. m.	2 19	Female.	10 0	80
Do.	do.	do.	2 0	do.	2 0	Aug. 12, 9 a. m.	2 0	Aug. 13, 9 a. m.	2 0	Aug. 18, 9 a. m.	3 0	do.	11 5	80
July 31.	Aug. 8, 9 a. m.	Aug. 10, 9 a. m.	2 0	Aug. 13, 9 a. m.	3 0	Aug. 16, 9 a. m.	3 0	Aug. 21, 10 a. m.	3 1	do.	3 0	do.	13 1	80
Aug. 1.	Aug. 9, 9 a. m.	Aug. 11, 9 a. m.	2 0	Aug. 12, 2 p. m.	1 5	Aug. 11, 9 a. m.	1 19	Aug. 16, 9 a. m.	2 0	Aug. 19, 2 p. m.	3 5	do.	10 5	80
Do.	do.	do.	2 0	Aug. 13, 2 p. m.	2 5	do.	2 0	Aug. 17, 9 a. m.	1 19	Aug. 17, 9 a. m.	4 0	do.	11 0	80
Do.	do.	do.	2 0	Aug. 13, 2 p. m.	2 5	do.	2 0	do.	1 19	do.	4 0	do.	12 0	80
Do.	do.	do.	2 0	Aug. 13, 9 a. m.	2 0	Aug. 14, 2 p. m.	1 7	Aug. 16, 2 p. m.	1 22	Aug. 20, 9 a. m.	3 19	do.	11 0	80
Aug. 2.	Aug. 10, 9 a. m.	Aug. 13, 9 a. m.	3 0	Aug. 15, 2 p. m.	2 5	Aug. 17, 9 a. m.	1 19	Aug. 20, 9 a. m.	3 0	do.	3 0	Male.	13 0	80
Aug. 3.	Aug. 11, 9 a. m.	do.	2 0	do.	2 5	do.	1 19	Aug. 19, 2 p. m.	2 5	Aug. 22, 9 a. m.	3 0	Female.	11 5	80
Do.	do.	do.	2 0	do.	2 5	do.	1 19	Aug. 21, 9 a. m.	2 5	Aug. 22, 2 p. m.	3 0	do.	11 5	80
Do.	do.	do.	2 0	do.	2 5	do.	1 19	Aug. 21, 9 a. m.	2 5	Aug. 22, 2 p. m.	3 0	do.	11 5	80
Aug. 5.	Aug. 16, 9 a. m.	Aug. 17, 9 a. m.	1 0	Aug. 19, 4 p. m.	2 7	Aug. 23, 9 a. m.	2 17	Aug. 25, 9 a. m.	2 0	Aug. 28, 9 a. m.	3 0	Male.	11 0	80
Do.	do.	Aug. 17, 2 p. m.	1 5	Aug. 17, 2 p. m.	2 0	Aug. 23, 9 a. m.	3 5	Aug. 24, 2 p. m.	2 0	Aug. 27, 2 p. m.	3 0	do.	11 0	80
Aug. 6.	Aug. 17, 2 p. m.	Aug. 21, 9 a. m.	2 19	do.	1 0	Aug. 24, 2 p. m.	2 5	Aug. 31, 9 a. m.	4 19	do.	4 19	do.	11 19	80
Do.	Aug. 19, 9 a. m.	Aug. 21, 2 p. m.	2 5	do.	2 0	Aug. 25, 2 p. m.	2 0	Aug. 28, 9 a. m.	2 19	do.	3 0	Female.	12 0	80
Average.			2.25+ 0		1.79+ 0		2 0		2 0		3.04 0		12 0	79.95
Oct. 2.	Oct. 11, 9 a. m.	Oct. 13, 2 p. m.	2 5	Oct. 16, 9 a. m.	2 19	Oct. 19, 9 a. m.	3 0	Oct. 22, 9 a. m.	3 0	Oct. 27, 9 a. m.	5 0	Male.	16 0	71
Oct. 3.	do.	do.	2 5	do.	2 19	Oct. 18, 9 a. m.	2 0	Oct. 21, 9 a. m.	3 0	Oct. 25, 9 a. m.	2 1	Female.	14 0	71
Oct. 2.	do.	do.	5 0	Oct. 16, 9 a. m.	1 5	Oct. 19, 9 a. m.	1 19	Oct. 22, 9 a. m.	3 0	Oct. 27, 9 a. m.	5 0	Male.	16 0	71
Oct. 2.	do.	do.	2 5	Oct. 17, 2 p. m.	3 19	do.	2 0	do.	3 0	do.	5 0	do.	16 0	71
Oct. 3.	do.	do.	2 5	Oct. 16, 9 a. m.	2 19	Oct. 19, 9 a. m.	3 0	Oct. 22, 9 a. m.	4 0	Oct. 28, 9 a. m.	5 0	Female.	17 0	71
Average.			2.6 0		2.6 0		2.2 0		3.2 0		4.8 0		15.8 0	71

Body: Widest at the head and thorax, caudal end bluntly pointed when viewed from the dorsum.

Legs: Femur covered with long sparse hairs; tibia covered with numerous short, stiff, appressed hairs; tarsi covered with numerous short, stiff hairs, end of tarsi having two small hooks.

SECOND INSTAR.

Fig. 12.

Length 0.81 mm., width 0.27 mm. at widest part of the body. Thorax and abdomen pale green, appendages clay color. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.32 mm.; of three joints, dark at apex, sucking tube brownish. Antennae tubular, of four joints, the first slightly swollen; amber colored, pubescent, hairs somewhat appressed; first joint 0.08 mm. in length, second 0.22 mm., third 0.25 mm., fourth 0.24 mm., total 0.79 mm.

Body: Each segment with sparse, short, stiff hairs. Body widest at fifth abdominal segment, tapering bluntly at posterior extremity.

Legs: Amber colored, femur covered with long, sparse hairs; tibia bearing short, stiff, appressed hairs; tarsi bearing numerous short, stiff hairs, end of tarsi having two small hooks.

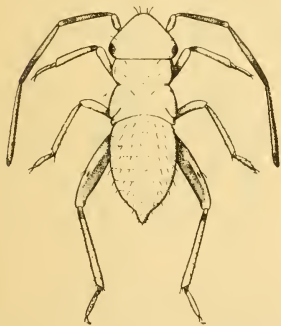


FIG. 12.—*Halticus citri*: Second nymphal instar. Greatly enlarged.

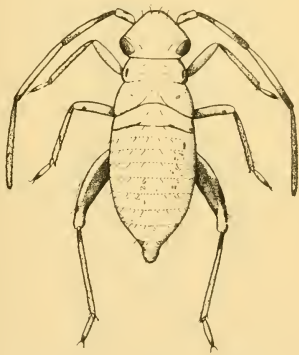


FIG. 13.—*Halticus citri*: Third nymphal instar. Greatly enlarged.

THIRD INSTAR.

Fig. 13.

Length 1.03 mm., greatest body width 0.32 mm., width of head at widest point 0.29 mm.

Head brownish, thorax and abdomen varying in color from pale to dark green, appendages amber colored. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.38 mm. long, three-jointed, amber colored, terminal joints dark at apex. Sucking tube brownish. Antennae tubular, four-jointed, amber colored, pubescent, hairs somewhat appressed; first joint 0.29 mm. in length, second 0.31 mm., third 0.22 mm., fourth 0.13 mm., total length 0.95 mm.

Body: Number of joints as in preceding instar. On dorsum of each joint one short, stiff hair and on lateral side of dorsum one stiff hair. Color pale green. Body widest at fifth abdominal segment, tapering bluntly at posterior extremity.

Legs: Femur covered with long, sparse hairs; tibia bearing short, stiff, appressed hairs, tarsus bearing numerous short, stiff hairs, end of tarsi having two small hooks.

FOURTH INSTAR.

Fig. 14.

Length 1.21 mm., width of body at widest point 0.44 mm., width of head at widest point 0.32 mm. Thorax and abdomen light to dark green, head brownish. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.56 mm. long, of three joints, terminal joints dark at apex, sucking tube dark brown. Antennae tubular, of four joints, the first slightly swollen; amber colored, pubescent, hairs somewhat appressed; first joint 0.15 mm. in length, second 0.38 mm., third 0.42 mm., fourth 0.40 mm., total 1.35 mm.

Body: Number of joints as in preceding instar. On dorsum of each joint are short, sparse, stiff hairs and on the side one short, stiff hair. Body light to dark green, wider than head at widest point, and tapering bluntly at posterior end.

Legs: Straw colored, femur covered with long, sparse hairs; tibia covered with numerous short, stiff, appressed hairs; tarsus bearing numerous short, stiff hairs.

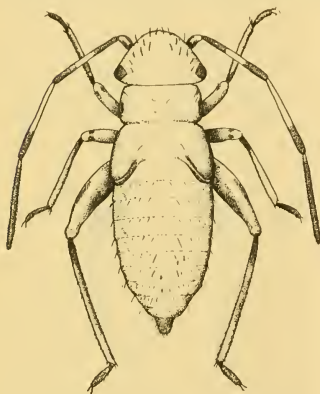


FIG. 14.—*Halticus citri*: Fourth nymphal instar. Greatly enlarged.



FIG. 15.—*Halticus citri*: Fifth nymphal instar. Greatly enlarged.

FIFTH INSTAR.

Fig. 15.

Length 2 mm., width 0.98 mm. at widest point two-thirds of the way back from anterior end, height or depth of head 0.40 mm., widest point of head over the eyes 0.51 mm. Color of head brownish, of thorax and abdomen pale to dark green. Eyes lateral and prominent, oval shaped, with hexagonal facet structure, color carmine. Beak 0.95 mm. long, of three joints, terminal joints dark at apex, sucking tube dark brown. Antennae tubular, of four joints, amber colored, pubescent, more densely at apex, hairs somewhat appressed; first joint 0.19 mm. in length, slightly swollen; second 0.64 mm., tubular, slightly enlarged, and brown; third 0.64 mm., tubular, slender, pale; fourth 0.56 mm., tubular, slender, tapering acutely; total length 2.03 mm.

Body: Abdomen with each joint bearing a short, stiff hair. Body dark green with dark wing pads, wider than head at widest point and tapering bluntly at posterior end.

Legs: Femur bearing long, stiff hairs; tibia bearing numerous short, stiff, appressed hairs; tarsus bearing numerous short, stiff hairs.

LIFE HISTORY AND HABITS.

Difficulty was experienced in securing life-history records during the months of June, July, and August, because of excessive heat. Much patience was needed to bring the adults through the months of January and February, the natural hibernating period. To have the specimens under close observation it was necessary to confine them under more or less artificial conditions. The death rate under these conditions was very high. The combined lengths of the egg, nymphal, and adult stages under conditions at Columbia, S. C., varied with the temperature, being from 58 to 94 days, with an average of 76 days for all conditions.

MATING.

Mating usually takes place soon after the individual reaches maturity. In the series of experiments conducted by the author it took place from 5 minutes to 2 hours and 30 minutes after the last instar matured, usually occurring in the daytime. The time covered in the process of mating as recorded in a series of six experiments ranged from 30 minutes to 1 hour and 35 minutes. After mating, the individuals in each case were observed to move in opposite directions and seek suitable places for feeding.

The brachypterous females are much more abundant throughout the year and were used in nearly all of the life-history experiments. The macropterous female, however, which is very rare, was found to be fertile and to deposit fertile eggs as does the brachypterous form.

OVIPOSITION.

During the spring, summer, and fall, oviposition begins about 4 days after mating according to Tables VI and VII, and was observed to take place principally during the night or early morning (see Table VII).

Individuals of *Halticus citri* almost invariably oviposit on those portions of the plant where previously they have been feeding, the leaves usually being selected with a preference for the upper side (see Tables I, II, and III). In some instances, however, during the late fall and winter in cage experiments (see fig. 16) it was observed that oviposition took place in the stem of the plant and also in the cork which constitutes the bottom of the cages.

TABLE VI.—*Incubation records of eggs obtained from one female of the garden flea-hopper, Columbia, S. C., 1915*

Cage 15-631.

Deposited—		Hatched—		Incubation period.	Deposited—		Hatched—		Incubation period.
Date.	Number of eggs.	Date.	Number of eggs.		Date.	Number of eggs.	Date.	Number of eggs.	
July 28...	4	Aug. 5	All.	8	Aug. 17...	0			Days.
29...	2	do.	All.	7	18...	0			
30...	2	do.	All.	6	19...	0			
31...	6	Aug. 8	All.	8	20...	0			
Aug. 1...	4	Aug. 11	All.	10	21...	0			
2...	7	do.	All.	9	22...	0			
3...	2	Aug. 9	All.	6+	23...	3	Sept. 2	All.	10
4...	4	Aug. 14	All.	10—	24...	0			
5...	2	Aug. 11	All.	6+	25...	1	Sept. 2	All.	7
6...	1	Aug. 14	All.	8	26...	0			
7...	0				27...	0			
8...	0				28...	1 ♀	Sept. 5	All.	8
9...	10 ♂				29...	0			
10...	4	Aug. 19	All.	9	30...	0			
11...	0				31...	0			
12...	0				Sept. 1...	10 ♂			
13...	0				Total.....	43			
14...	0				Average incubation				8
15...	0								
16...	0								

¹ Dead.

General average of 1.34 per day for 32-day period.

TABLE VII.—*Daily and total production of eggs deposited by one female of H. citri, time of hatching, and length of incubation period, Columbia, S. C., 1916.*

Cage 15-1080.

Deposited—				Hatched—		Incuba- tion period.
Date.	Number of eggs.			Date.	Number of eggs.	
	Day.	Night.	Total.			Days.
Sept. 4.	1		1	Sept. 14.	All.	10
5.		1	1	Sept. 15.	All.	10
6.		6	6	do.	All.	8
7.		3	3	Sept. 14.	All.	8
8.		1	1	Sept. 16.	All.	8
9.	3	2	5	Sept. 18.	All.	9
10.		4	4	do.	All.	8
11.	7	2	9	Sept. 20.	All.	9
12.		3	3	do.	All.	9
13.	9	3	12	Sept. 22.	All.	9
14.	4		4			
15.	6	2	8	Sept. 24.	All.	9
16.	4	1	5	Sept. 25.	All.	9
17.	4	6	10	Sept. 26.	All.	9
18.		1	1	Sept. 27.	All.	9
19.		2	2	Sept. 28.	All.	9
20.	3	2	5	Sept. 29.	All.	9
21.		1	1	do.	All.	8
22.		4	4	Sept. 30.	All.	9
23.		1	1	Oct. 1.	All.	7
24.		1	1	Oct. 2.	All.	7
25.	0	0	0		0	0
26.	3	3	6	Oct. 5.	All.	10
27.	3	3	6	Oct. 6.	All.	10
28.		2	2	Oct. 13.	0	
29.		3	3	Oct. 9.	All.	10
30.		3	3	Oct. 10.	All.	10
Oct. 1.	0	0	0			
2.		2	2	Oct. 10.	All.	9
3.	2		2	Oct. 11.	All.	9
4.		2	2	Oct. 12.	All.	8
5.	2		2	Oct. 14.	All.	8
6.	2		2	do.	All.	8
7.	0	0	0			
8.		1	1	Oct. 15.	All.	8
9.		2	2	Oct. 17.	All.	8
Nov. 3.	♂	Dead.				
Total.	53	67	120			
Average.						8.04

The female assumes the usual feeding position in which the body is parallel with the surface of the leaf. Apparently after a desirable place is located with the proboscis a puncture is made; the curved or swordlike ovipositor is then advanced to the puncture made by the proboscis immediately after the removal of the proboscis; the ovipositor penetrates the puncture to its full length, and an egg is deposited in the cavity. After the ovipositor is withdrawn a large drop of clear fluid exudes from it, covering the exposed truncate end of the egg.

The process of oviposition requires about 15 to 20 seconds, only one egg being placed in each hole.

EFFECT OF TEMPERATURE ON OVIPOSITION.

It was found that oviposition ceased when the temperature fell below 70° F., and there were no records of oviposition at temperatures above 90° F. In a number of cages (fig. 16) each containing two male and one female flea-hoppers were placed in a well-ventilated basement room of the laboratory, the temperature of which ranged between 75° and 90° F., most of the eggs were deposited in the daytime when a temperature of about 80° F. was reached, which usually occurred in the early morning.

EGG STAGE AND PROCESS OF HATCHING.

Several days before hatching the egg changes from its original pearly white to a pale clay-yellow color, this change being evidence of its fertility. The color of the egg resembles that of the nymph at emergence. The shape and position of the nymph, including the segments of the abdomen, the thorax, the head, the appendages, and the carmine-colored eyes, are distinguishable under a lens. In the egg the nymph is found with its head at the truncate end a short time before hatching, the covering of this end being broken at the edge or through the middle, and opening, in most cases, like a trap-door. The head appears through the opening followed by the thorax and abdomen. The body moves backward and forward in an effort to disengage the appendages from the chorion. The appendages are all laid snugly against the ventral side of the body. The proboscis is the first appendage to be released, followed by the prothoracic and mesothoracic legs. These are then utilized to free the antennæ and metathoracic legs. The entire process requires about one hour.

The egg is slightly swollen before hatching. Following the emergence of the nymph the eggshell collapses and is semitransparent with red pentagonal to polygonal markings. The body and legs of the freshly emerged nymph are pale clay-yellow color, the antennæ straw color, and the eyes carmine. The egg period was found to range from a minimum of 6 days to a maximum of 16 days in the experiments carried out, with an average incubation period of 11 days.

NUMBER AND LENGTH OF INSTARS.

There are five instars. The length of the instars as well as the total length of the nymphal life is slightly variable, as may be noted by reference to Table V. What slight variations there were in the length of these instars may have been due, in large measure, to differences of temperature and food supply.

The intervals between each two instars gradually increases as maturity is reached. There was found to be no relation between the length of the periods and the sex of the individual.

LENGTH OF LIFE OF THE ADULT.

Adults of *Halticus citri* lived for from 9 to 94 days in the rearing experiments, as is shown in Table VIII. The sexual development was found to be complete as soon as they became adults. The females are shown to have lived longer than the males.

TABLE VIII.—*Length of life of adults of Halticus citri.*

No.	Male.			Female.		
	Emerged.	Died.	Days.	Emerged.	Died.	Days.
1.....	July 10	Aug. 9	30	July 13	Aug. 29	42
2.....	July 13	Aug. 26	44	...do....	Aug. 10	28
3.....	July 10	July 19	9	July 15	Aug. 31	47
4.....	...do....	...do....	9	July 12	Aug. 6	25
5.....	July 13	July 26	13	Aug. 15	Sept. 10	26
6.....	Aug. 17	Aug. 30	13	Aug. 17	Sept. 2	16
7.....	Aug. 18	Sept. 10	23	Aug. 31	Nov. 3	64
8.....	Oct. 27	Dec. 22	26	Oct. 27	Jan. 13	78
9.....	...do....	Jan. 29	94	Oct. 28	Jan. 16	70
	Av.		29.3	.....		44

HIBERNATION.

In experiments carried out by the writer, the last remaining individuals of the adults which had emerged on October 27, 1915, died on January 29, 1916. Other adults of both sexes issued December 18, 1915, and hibernated until March 14, 1916, when they became active again. Eggs were found in the cage on this date. First-stage nymphs were discovered on April 2, 1916.

The garden flea-hopper is found in greatest abundance during August and September, and gradually decreases in number as winter approaches. In the latitude of Columbia, S. C., mortality is greatest in December, very small numbers being found after this date. Many of the adults apparently are killed by the cold weather, and the remainder seek winter protection under the thickest bunches of their favorite host plants, along fences and other well-protected places, where they continue to winter until the plants become green again in the spring, and then deposit eggs before perishing.

SPRING APPEARANCE AND NUMBER OF GENERATIONS.

The adults of the garden flea-hopper in the latitude of Columbia, S. C., usually appear about the middle of March. Much depends upon the season, however, and they have been found soon after the host plants become green and spring is well in evidence. The adults appeared and deposited eggs as early as March 14, 1915, in the field experiments at Columbia, which was the earliest date recorded of the discovery of eggs in the outdoor experiments. Eggs have been secured in the outdoor cages throughout the year, beginning with the middle of March and continuing until the last of November. From five to six generations were reared at the Columbia laboratory. The length of life of each individual is determined largely by the length of life of the adult stage, this being the longest period of the life cycle.

The first generation was found to extend from March 14, 1915, when fertile eggs were first deposited, to May 15, 1915; the second generation extended from May 15 to July 12, 1915; the third from July 12 to September 11; the fourth from September 11 to November 18, and the fifth from November 18, 1915, to February 10, 1916.

FEEDING HABITS.

In almost every instance noted the youngest plants are attacked in preference to the older and more vigorous growths, and when the insects start feeding on a plant they apparently continue until all the sap is extracted, giving the plant a bleached appearance. During the warm seasons the tendency is to feed at the top of the plants, but during cool days and seasons they feed rather at the bases of the plants. It has been noticed that during warm days the individuals seem to show no particular inclination for protection from the sun by seeking the shady side of the leaf. When they are disturbed, however, they immediately seek a place of concealment on the plant or hop to the ground in quest of protection.

In feeding on the host plant, the individual places itself in a position parallel to the surface of the leaf, preferably on the upper surface, with its legs resting on the surface. Then the proboscis is swung down from the ventral side of the body to a perpendicular position and the apex is thrust into the epidermis of the leaf at a point midway between the prothoracic legs, the proboscis is hinged at the second articulation, the head and thorax being bent slightly downward to allow the first and third articulations to meet, the sucking tube remains straight as the open sheaths of the second and third segments leave the sucking tube, and a slight pressure is placed on the apex of the proboscis. A mechanical procedure ensues similar to the pumping process, in which the head and thorax move slightly upward and downward, not sufficiently, however, to straighten the

second and third joints of the proboscis. Probably in this pumping procedure the food is taken into the body through the proboscis. After continuing this process for several minutes at a time the proboscis is straightened and drawn from the tissue of the leaf and swung to its natural position on the ventral surface of the body for a short time; then it is again swung down and cleansed by a stroking process with the forelegs which clasp the proboscis between the tarsal joints. After gradually sliding the proboscis through them the insect starts feeding again.

This habit has been noted alike in all ages of the nymph and adults, both males and females.

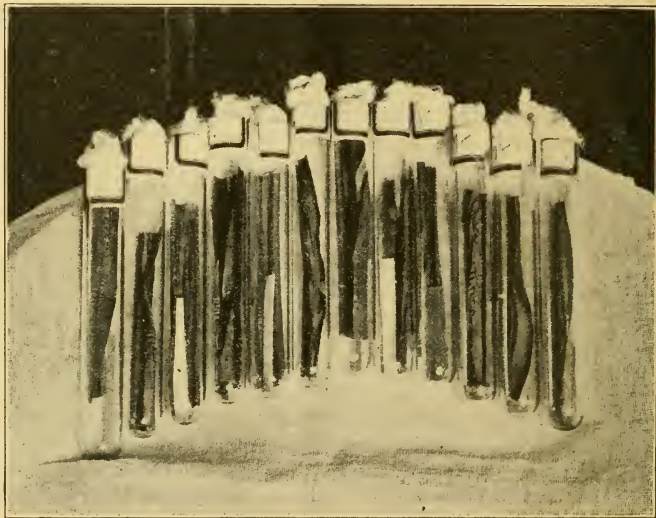


FIG. 16.—Type of cage used in conducting molting experiments with the garden flea-hopper.

PROTECTIVE HABITS.

Both the males and females are saltatorial, as the metathoracic legs are much longer and stronger than the others. The male is found to be decidedly more active than the brachypterous female, a fact probably due to the possession, in addition, of true wings. The adult individuals generally are active and strong as runners and hoppers. When they are only slightly disturbed they hasten immediately for concealment to the opposite side of the leaf of the plant. If the approaching object, however, appears with a violent disturbance, the individual will hop many times its own length to the ground or to another plant where immediate protection may be found.

In a number of experiments different individuals were placed on a large horizontal screen within the room, and the distance of jumps made on the screen ranged from three inches to nearly three feet. In the latter instances they seemingly sustained themselves in the air by the aid of their wings.

The nymphs of the first stage are not saltatorial until nearly time for molting; when disturbed, then, they show slight saltatorial tendencies but are usually very quiet even when disturbed, and merely move slowly to another position on the plant out of danger. They feed on the same place sometimes through several instars. The last three or four instars of the nymph have the same habits of locomotion and are as active as the adults.

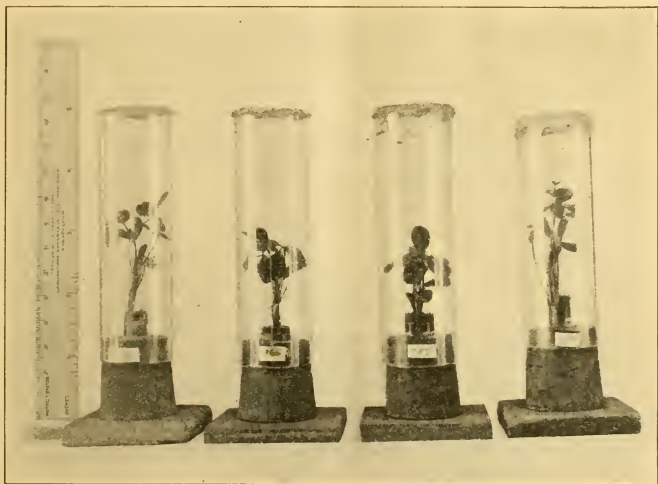


FIG. 17.—Type of cage used in conducting rearing experiments with the garden flea-hopper.

REARING METHODS.

Some difficulty was experienced in acquiring a satisfactory and serviceable rearing cage for the different experiments carried on with this species. Test tubes (fig. 16) were first used as containers for molting experiments and lamp-chimney cages for life-history work. The inaccuracy of the results with these rearing cages necessitated the substitution of one which would be more convenient. The best results were obtained with rearing cages constructed of 1 and 2-inch glass cylinders with cork bases and cloth tops sealed at the edges with glue (fig. 17), each cork base containing 9 by 36 mm. vials with water, and plant food for the insects. The 1-inch cages were attended with greatest success in molting experiments, while the 2-inch cages were used with advantage in life-history work.

NATURAL ENEMIES.

Repeated observations have shown that because of the alertness and saltatorial habits of the nearly grown nymphs and adults of the garden flea-hopper their chances of being attacked by natural enemies are somewhat meager. The nymph in the earlier stages, however, is known to be less active and is frequently attacked by the larva of a small red predacious mite of the family Erythraeidae. The writer also reared a number of egg parasites which have been determined by A. G. Gahan as representing the following species:

Anaphes perduebuis Girault.

Tetrastichus sp.

Gonatocerus sp.

Anagrus armatus nigriventris Gir.

Westwoodella americana Ashm.

Abbella subflava Gir.

These species have been reared from the eggs of the garden flea-hopper collected from the alfalfa fields where the outbreaks occurred, and the parasites were believed to have rendered an appreciable amount of good.

REMEDIAL AND PREVENTIVE MEASURES.

Since the garden flea-hopper has an extremely wide range of food plants, though alfalfa is one of its favorite hosts, rotation as a remedy would be out of the question. Clean culture, however, to prevent hibernation in weeds and trash was found to result favorably in controlling the overwintering adults and is the most adequate means thus far devised of reducing the numbers of the pest.

In alfalfa fields where outbreaks of the garden flea-hopper occurred it was observed that timing the removal of the crop so as to destroy the eggs was a vital factor in control. Although a small percentage of the eggs is laid near the ground, the larger proportion is deposited in the delicate leaves and petioles. Some of these leaves containing eggs drop to the ground, it is true, and in numerous cases these eggs hatch; nevertheless, timely cutting will remove the larger number, and this measure is recommended in controlling an outbreak.

DUSTING AND SPRAYING TESTS IN THE FIELD.

A dusting experiment was conducted in one of the alfalfa fields where an outbreak of the garden flea-hopper occurred, the damaged crop being cut and removed from the infested field. An area of 100 square feet was selected and treated thoroughly with a mixture of air-slaked lime and flowers of sulphur in equal proportions. The mixture was thoroughly applied with a hand duster, one application being made in the morning and another at midday. Repeated observations by the writer after the dusting was completed failed to show that the treatment had been effective on any stages of the flea-hopper.

In the same field a plat of similar size was treated with a spray solution composed of potassium sulphid and water at the rate of 1

ounce of the potassium sulphid to 5 gallons of water, a hand sprayer of the compressed-air type being used. The plat was thoroughly sprayed in the morning and also at midday, but even when a stronger solution was employed there was little appreciable benefit from the application.

A spray of kerosene emulsion was next tried on three experimental plats of alfalfa, each having an area of 100 square feet. The alfalfa had been cut and removed a few days before, and the moist weather was causing the new crop to grow rapidly. The stock emulsion was prepared by the following method: One-half pound of laundry soap was dissolved in 1 gallon of hot water; the solution was then removed from the fire, and after 2 gallons of kerosene had been added the material was violently agitated. The table of strengths, as applied in their order on the three plats, follows:

7 per cent strength, $8\frac{1}{2}$ gallons of water added to 1 gallon of stock solution.

10 per cent strength, $5\frac{3}{4}$ gallons of water added to 1 gallon of stock solution.

12 per cent strength, $4\frac{1}{2}$ gallons of water added to 1 gallon of stock solution.

Observations were continued for one day after the spraying experiments were started, and the following results were recorded: The 7 per cent kerosene emulsion was very effective in destroying the garden flea-hopper in all stages; the 10 per cent solution killed practically all the flea-hoppers and did not materially affect the alfalfa; the 12 per cent solution destroyed all of the insects but damaged the alfalfa crop noticeably.

In the campaign against the garden flea-hopper about 12 acres of fields where the most severe outbreaks occurred were sprayed with 10 per cent kerosene emulsion with great success. The solution was applied with an orchard power sprayer having two nozzles, the spray being delivered from the machine at a gauge pressure of 80 pounds and covering a strip 18 feet wide. The machine was driven by a team of mules, and the nozzles were operated by two men at the rear of the machine. An average of 30 gallons was applied to each acre. The cost per gallon of the solution was about 4 cents, thus making the estimated cost per acre \$1.20, nothing being added for labor and machinery, since the farmers had these at their immediate disposal. Since it was estimated that the yield of hay would be a ton per acre under normal conditions, and since spraying with kerosene emulsion as described costs approximately \$1.20 per acre and effects an almost complete saving of the crop, the market price of which has been \$20 per ton, this treatment may be recommended as a satisfactory and economical measure of control.

The only other method of control which effectively overcame the pest was the plowing under of the infested crop, which was done in a number of cases where many of the plants had been killed by the

insect. There are objections to this measure, however, particularly in fields having a good stand. Much labor and expense are required to make a seed bed and to crop the land, and a measure which would involve repetition of these operations would tend to discourage the growing of alfalfa.

SUMMARY.

One of the most striking hemipterous forms of the family Capsidae is the garden flea-hopper, *Halticus citri* Ashm. The male adult has the typical capsid form with long wings, while the female adult differs in appearance, being wingless with a convex robust figure suggesting to the observer a new species. Rarely, female adults are found which resemble the males in general appearance, except that they are more robust and have long wings; this form, however, upon close observation is found to be a trifle larger with a more robust body together with a more perfectly shaped head and thorax, and its genitalia resemble those of the wingless female.

The individuals hop and jump about in the meadow in the manner of leafhoppers. The males are more active than the females, probably because they have functional wings.

In South Carolina and Georgia these insects become abundant in early summer and continue so until late fall, when they gradually disappear, the older individuals dying and the younger seeking hibernation quarters under or at the base of their favorite host plants and in protected places such as fences, terraces, or shrubbery.

Both nymphs and adults suck sap from punctures made in the leaves, petioles, and stems of the plants, causing discoloration, wilting, and, in severe infestation, death.

Leguminous plants appear to constitute its favorite foods and places for breeding, although its range of host plants is extremely wide.

The eggs are deposited in the leaves and petioles of the food plants, usually in places where adults have been feeding.

The incubation period of the egg at Columbia, S. C., covered from 6 to 16 days with an average of 11 days. The five instars of the nymph stage together cover from 10 to 18 days with an average of 14 days. The combined length of nymph and adult stages was 25 days.

In the latitude of South Carolina there are from five to six generations annually. The species was found to hibernate in the adult stage.

The garden flea-hopper is little affected by natural enemies, but changes in weather reduce its numbers during the winter months.

Hibernation and subsequent multiplication are prevented where weeds and plants that remain green late in the fall and resume growth in the spring are cleaned up in the fall and destroyed.

In the case of severe outbreaks of the garden flea-hopper it is advisable to cut and remove the invaded crop and then spray the field with a 10 per cent solution of kerosene emulsion.

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DIV. ENTOMOL.

UNITED STATES DEPARTMENT OF AGRICULTURE
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Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.



October 18, 1921

**CONTROL OF THE ARGENTINE ANT IN
CALIFORNIA CITRUS ORCHARDS**

By

R. S. WOGLUM, Entomologist, and A. D. BORDEN, Scientific
Assistant, Fruit Insect Investigations

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INTRODUCTION.

Supposedly introduced into the United States at the close of the nineteenth century the Argentine ant (*Iridomyrmex humilis* Mayr) has since become widely distributed through the more temperate regions, where its complete occupancy, in long-infested localities, and its omnivorous habit bear an important relation to crop production and food storage and rank it as one of the most annoying of household pests. Its discovery in 1908 in cities bordering San Francisco Bay resulted in the initiation of a control campaign under the direction of Prof. C. W. Woodworth, of the University of California, and subsequently led to the development of an arsenical poisoned sirup of considerable merit.

The Argentine ant was recorded in citrus orchards in California almost from the date of its reported presence in the State. It appeared to cause no alarm to orchardists, however, usually remained unnoticed except about the buildings, and where observed was classed

¹ Photographs by senior writer; figure 3 drawn by Miss A. Motter. Mr. Woglum resigned from the Bureau of Entomology September 11, 1920.

merely as "an ant" whose presence was believed in no way detrimental to the trees. The rôle of the Argentine ant as an orchard pest in California was discovered by Mr. J. D. Neuls and the senior writer in 1915 while conducting an investigation of the common mealybug, and its very direct bearing on the control of the mealybug was conclusively proved by an extended series of experiments. This immediately led to an investigation into methods of ant control with which the junior writer became associated in 1917. The great success which attended these experimental efforts led to control demonstrations of considerable proportions in severely ant-infested communities and proved a stimulus to widespread interest in the pest. The demand for relief which followed this awakened interest has already resulted in the treatment of several thousand acres, from a very large part of which the ants have been totally eradicated. This bulletin presents the results of the various remedial methods pursued during the period 1915-1920 and gives full instructions for the control and eradication of ants in the citrus orchards of California.

RELATION OF THE ANT TO THE CITRUS INDUSTRY.

The spread of the Argentine ant in California bears an important relation to citrus growing, a relation certain to become more prominent with wider distribution and long-established infestations. The very severe damage which this pest can sometimes do in citrus orchards has been impressively stated by Newell and Barber² as follows: The bearing qualities of an orchard are severely impaired by the second season of infestation, the crop is almost entirely lost by the third season, and the trees are dying by the fourth year of infestation. This conclusion is based on conditions in Louisiana, and in this respect it should be noted that no systematic effort is made in that State to control citrus scale pests. Such extreme damage has never been observed under California orchard conditions where fumigation and other insecticidal control measures are practiced constantly.

The damage to trees in ant-infested orchards in California does not arise from direct attacks on the blossoms, fruits, and roots, as has been reported from some regions, but is attributable very largely to its so-called symbiotic manner of living with mealybugs, aphids, and various scales, which results in their increase beyond all customary proportions. The constant attendance of the ant protects the mealybugs or scales from their natural enemies and results in their abnormal increase. (See fig. 1.) The degree of infestation is further stimulated and extended through the fact that the ant distributes these injurious insects to other parts of the tree or even

² NEWELL, WILMON, and BARBER, T. C. THE ARGENTINE ANT. U. S. Dept. Agr., Bur. Ent. Bul. 122, p. 192. 1913.

to adjacent trees. The chief damage done by the Argentine ant in California citrus orchards has been through its relation to mealybug infestations, particularly the common mealybug, *Pseudococcus citri* (Risso). Prior to the reported presence of this ant in the Southwest, one species of mealybug was recorded as a serious citrus pest in only three or four limited districts, where it was characterized by sporadic outbreaks which would quickly disappear. In the last decade, which is contemporaneous with the Argentine ant invasion, the severe infestation of the common mealybug has increased many hundred per cent and districts have been invaded from which mealybugs were never before recorded.

In the course of investigations under the direction of the senior writer to establish effective control of the common mealybug, *Pseudococcus citri* (Risso), it was discovered that the Argentine ant not only brings about increased severity of infestation but causes the mealybug to persist year after year. It was furthermore discovered that the common mealybug was attacked by many predatory insects, some of such high efficiency that in ant-free territory they were capable of keeping the mealybug under commercial control except at those infrequent periods normal in the "ups and downs" of biologically controlled pests. Demonstrations carried out in several mealybug-ant infested orchards in the San Gabriel Valley during the years 1915 and 1916, in which alternate rows were kept free of ants, proved that trees rid of ants quickly become freed of mealybugs, although on adjacent ant-attended trees the mealybug infestation persists. The results of these demonstrations are verified by the fact that in every experiment performed by the writers during the period of 1915-1920 equally good results have been obtained. The



FIG. 1.—Ants attending a group of mealybugs. Their almost constant presence protects the mealybug from its natural enemies.

eradication of the ant in every instance resulted in a reduction of the mealybug infestation to commercial control within a period of from 1 to 3 months. This has been largely due to the increased and unrestricted activity of predatory insects already established.

The citrophilus mealybug, *Pseudococcus gahani* (Green), was first recorded as an orchard pest in 1914 and has never been observed as a severe pest in citrus orchards except in localities infested with the Argentine ant.

The influence of the ant on increased severity of scale pests, while less important than on mealybugs, must be considered. The black scale, *Saissetia oleae* (Bern.), and soft brown scale, *Coccus hesperidum* L., have been observed to become decidedly more numerous on trees attended by large numbers of ants than in other parts of the same orchard entirely free of the ants. Trees severely infested with the soft brown scale have been rapidly freed by the action of parasitic insects following the control of this ant.

It is entirely possible that the Argentine ant distributes fungous and bacterial diseases, although no specific evidence has been noted. Attracted as they are by the honeydew of insects, their habit of carrying this and various other substances, both animal and vegetable, their colonization and movement over the ground, and their constant attendance to all parts of the trees offer ready means of distributing brown rot, gum disease, and other maladies of citrus. In this connection ants would appear to be especially deserving of attention in pear orchards through their possible relation to blight.

OTHER RELATIONS.

Beekeeping in sections heavily infested with the Argentine ant is most difficult and proves successful only after a strenuous campaign is instituted to control or exterminate the pest. The ant is exceedingly fond of honey and, furthermore, attacks the bee larvæ. The ant's small size, great numbers, and persistent effort to reach desired food make it an enemy with which the bees are unable to cope long.

As a household pest the Argentine ant has proved particularly annoying. It invades all parts of the house in search of food, and the intolerable conditions brought about in heavily infested districts render the houses less desirable for places of residence.³

DISTRIBUTION.

The Argentine ant appears to have been first noted in California in 1905 by Dr. E. S. G. Titus, at Ontario, although it did not come into prominence until 1908, when a general survey of its dis-

³The rôle of this insect as a household pest has been fully described by Mr. E. R. Barber of this department in Farmers' Bulletin 1101, United States Department of Agriculture.

tribution was made by Prof. C. W. Woodworth, of the University of California. It was then reported as widely distributed about the San Francisco Bay region and in Southern California at Azusa and Upland. By 1910 the total territory involved was estimated at 4,000 acres in northern California and 1,000 acres in the southern part of the State. During the 10 years intervening between the second survey of Prof. Woodworth and to-day this ant has greatly extended its area of occupation, spreading into the great interior valleys of northern California, and including within its limits localities in every county in the south excepting one, as follows: Los Angeles, 39; San Bernardino, 8; Riverside, 4; Ventura, 5; Santa Barbara, 5; Orange, 10;



FIG. 2.—Present known distribution of the Argentine ant in Southern California.

San Diego, 6. Two heavy infestations have been observed on Catalina Island, off the mainland of Los Angeles County. (See fig. 2.) The infested territory appears to fall for the most part within cities and towns, although the country acreage concerned is very large, between 8,000 and 10,000 infested acres being known in citrus alone.

Elsewhere in the United States the Argentine ant has been reported to occur in settled localities throughout the Southern States, being established as far north as Nashville, Tenn., and Raleigh, N. C. First described from Argentina it has since gained a foothold in other parts of South America, in the Madeira Islands, South Africa, and Germany.

CHARACTERISTICS AND HABITS.

The Argentine ant, like most other species of ants, forms definite colonies or ant communities under the surface of the ground. The colony or nest is an elaborate system of galleries and cells, closely connected, with usually only two or three openings to the surface.

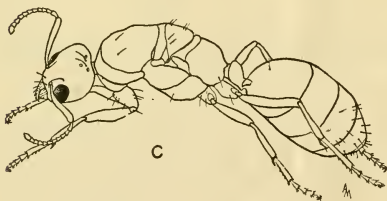
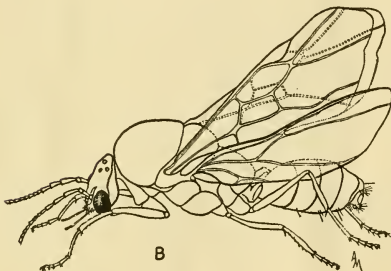
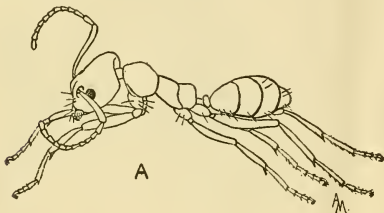


FIG. 3.—The Argentine ant: a, worker; b, male; c, queen.
(Greatly enlarged.)

Though the galleries may cover an area of over 10 square feet they seldom are more than 8 or 10 inches in depth. Colonies are located in places which will afford protection from excessive moisture and give the proper warmth; in orchards during the winter they are invariably on the sunny south side of the trees, usually just beyond the drip of the branches, but in summer they are more often on the east or north margin. In a well-infested orchard under cultivation each tree has a definite and complete colony. The favorite places for colonies about a residence are under cement sidewalks, the foundations of the buildings, a pile of rubbish, the compost heap, or a chicken yard.

The size of the community varies greatly with the season, the food supply, and the age of the colony. In a normal summer colony the ants will be found in all stages of development—eggs, larvæ, pupæ, workers, males, and females—and the colony responds quickly to warm days and an abundance of food by increasing its numbers. If the colony grows rapidly and the food supply warrants it, or if the food supply is some distance from the main colony, a new community will be started nearer the source of supply by a migration of part of the former colony along the trail established. This expan-

sion of the colony usually occurs in the early spring and summer months. In the late fall (November) the outpost communities are usually abandoned and large central winter colonies are formed in more favorable locations having better drainage and sun exposures. The activities in these communities are limited, fewer workers are sent out in search of food, the male form disappears, reproduction almost ceases, and the number of ants is reduced. Several colonies dug up in December, 1919, and January, 1920, showed a large number of workers in the colony with only a light trail going out in search of food, a number of females, no males, few if any eggs, a few matured larvæ, and numbers of pupæ. Renewed activities in these colonies and the division of the central colony usually occur in early April, though the time may vary somewhat with the season.

As stated, the summer colony is composed of three distinct forms of adults—workers, males, and queens. (See fig. 3.) The workers gather the food and attend to the labors of the community and are simply imperfect females with no reproductive capacity. They greatly outnumber the other forms and are the ones most commonly met with. The males, always winged, are the drones of the colony and have only one function, that of fertilizing the queen. The queens are the reproducing females and for a short time during the mating period are winged. They remain in the nest most of the time, but occasionally may be found out in the trails—a characteristic of this species (fig. 4). It is absolutely necessary that a fertilized queen accompany a number of workers if a new colony is to be established, as the workers alone have no means of reproduction.

The winters in southern California, though occasionally wet enough to retard the development of the ant colonies and force them to winter quarters, are so often broken by short, warm spells and the average rainfall is so light that trap nesting has proved ineffective and seldom are any of the colonies destroyed by excessive moisture.

The preferred food of the ants in orchards is the honeydew secreted by certain scales and aphids, the honeydew from blossoms, and the bodies of certain soft-bodied insects. The workers are very active in collecting this food and may be observed returning along the trail from a foraging expedition, their abdomens greatly distended with liquid food, or their strong mandibles securely clasping their prey. About residences the ants are more or less scavengers, feeding on bits of food wherever they can find it, but frequently invading pantries and even ice chests in search of meats, sugar, sirups, fruit, etc. Their trails may be extended to any part of the building in search of food and often during the first few hot days of summer the ants storm the house.

An interesting feature in the distribution of this ant is that it has completely replaced all native species, with possibly two exceptions,

wherever it has become established. Only on the margins of the Argentine ant infestations does one find colonies of the native Pre-



FIG. 4.—Characteristic trails of the Argentine ant on a tree trunk.

nolepis, Formica, and others. They have repeatedly been observed to dislodge the large red agricultural ant (*Pogonomyrmex californicus* Buckley) from its nest, though sometimes this species persists for a

considerable period. Often after the Argentine ant has been eradicated in an orchard by control means the native ants will come in, but gradually the area will be retaken by the imported ant unless prevented. In comparison to this it is interesting to note the social habits of Argentine ants among themselves. They do not fight one another nor do members of different colonies disagree. In fact, trails from different colonies often converge and an interchange of workers may take place.

The workers are active throughout the day and night and feed almost continuously if not affected by temperature conditions. On cool, foggy, or frosty mornings with a temperature below 50° F. the activity of the ants is greatly retarded and they become slow and sluggish in their movements. Small colonies become almost inactive. Only a small percentage of the workers leave the colony to forage, the majority remaining to protect and care for the ant nest.

CONTROL.

The development and spread of the Argentine ant appear to be governed very largely by food supply and meteorological conditions. From natural enemies such as exert a restraining influence on most injurious insects this species is remarkably free and no record of even temporary control by this means has come to notice in the history of the pest in this country. Therefore, artificial control is the one source of relief once the ant has become established.

The first efforts toward control of the Argentine ant on citrus trees in southern California were made in July, 1915, and confined to banding with commercial sticky tree-banding material, a substance widely used to prevent insects ascending plants. Further experiments in repressive measures, including the use of the sticky material compounded with other substances, banding with corrosive-sublimate tape, and the use of pyrethrum and sodium fluorid, were carried on until the appearance, during the latter part of 1916, of Bulletin 377 of this department, by E. R. Barber, which presented for the first time a successful method of ant eradication. The superiority of eradication over control by repressive measures was immediately apparent, and subsequent experiments have been carried out with this in mind.

BANDING.

STICKY TREE-BANDING MATERIAL.

EXPERIMENT 1.

During the latter part of September, 1915, an experiment with sticky tree-banding material was started in an orchard of 1,135 trees, each of which was attended by heavy trails of ants. Bands $3\frac{1}{2}$ to 5

inches in width were applied directly to the trunks and the ants above the bands removed by the use of insecticides. Inspections were made at least biweekly for a period of six weeks following the start of the experiment and these bands were refreshed at the time of inspection and the ants removed from the body of the tree. During the course of the experiment upward of 70 per cent of the trees became reinfested. The cost for labor and materials to keep the ants in this 10-acre orchard under control by the use of bands amounted to approximately 15½ cents per tree, proportioned as follows:

Labor for pruning and banding 1,135 trees.....	\$75. 00
Sticky tree-banding material.....	22. 80
Labor for inspection and treatment for ants.....	60. 00
Material for ant treatment.....	10. 00
Hand pump.....	10. 00
Total cost.....	177. 80
Cost per tree.....	0. 156

It was quickly determined that constant surveillance and frequent combing of these sticky bands are necessary to keep trees free of ants.

EXPERIMENT 2.

Another experiment was performed, in which 120 orange trees were banded with sticky tree-banding material February 21–25, 1916, after the method used in Experiment 1. The ants were present in very light trails, due to retarded development during the winter months. This experiment was inspected weekly for a period of four months, at each visit the bands being refreshed where necessary, infested trees freed of ants, and all growth beneath the tree removed. The results of this inspection are given beneath.

	Per cent of bands crossed.
March.....	37
April.....	5
May.....	10
June.....	14

The bands in this second experiment proved decidedly more effective than those in Experiment 1. This is attributable to several causes. The work was started at a time when the weather was cool and the ants not numerous. In fact they were not abundant at any time during the experiment with the exception of a very few trees on which the bands were not continuously effective. Colonies were removed to neighboring trees where food was abundant and, furthermore, the bands were continuously in a good state of repair. Experiment 1 was started in September when the ants were steadily streaming up every tree to attend heavy infestations of mealybugs.

The size of the orchard prevented each band receiving the same careful attention given in Experiment 2. Instances were noted during the autumn where the bands on slightly attended trees were bridged within an hour following the application.

CONCLUSIONS.

The conclusion to be reached from these two experiments is that the constant attention required to make sticky tree-banding material an effective barrier to ants on heavily infested citrus trees renders the method impracticable in orchard work. It might be used to advantage on a few trees which can be given the necessary attention, as, for instance, on house lots or about buildings.

The general belief that sticky tree-banding material is injurious to citrus trees when applied directly to the bark has been found erroneous. The writers have never seen a citrus tree killed as a result of this treatment. In 1915, 40 three-year-old nursery trees were banded. Examination of the bark beneath the bands one year after application showed the bark perfectly green and healthy. The sticky material on 100 trees banded in September, 1915, was scraped off in July, 1916. In no instance was there certainty of injury to the bark or cambium. Examination of hundreds of trees which have been banded with sticky material for periods ranging from 1 to 5 years have failed to show definitely a single instance of severe injury attributable to the bands. A disease known as gummosis is prevalent throughout southern California especially on heavy soils. Exudation of gum from this disease, beneath the bands or closely adjacent, and the accompanying diseased tissues revealed by removing the band, have been sometimes attributed to the banding with sticky material, although no cases have been observed where this was definitely the cause. Applications to trees soon soften the bark beneath somewhat. After about one year the exposed surface of the sticky material becomes glazed and by the second year a hard exterior coating is found and only the substance adjacent to the tree remains moist and sticky. In due time, depending on the thickness of the sticky layer, the entire band becomes hard, and subsequently is broken by the expanding growth of the trunk. The bark where exposed to the air dries and assumes its normal consistency and appearance. Heavy bands may require several years to dry.

Possible injury from sticky tree-banding material might arise from removal of heavy bands within a year following their application or before they are somewhat dried out. In one case trees heavily banded in September were scraped the following July. The bark was so injured by the workmen in removing the sticky material that a very weak solution of corrosive sublimate was used to disinfect

the wounds. The ultimate effect was such rapid drying of the scraped tissues that great flakes of bark peeled off, temporarily injuring the trees, although they soon recovered. When sticky bands are to be removed, therefore, this should be done without scraping the bark and the thin film will assure gradual drying of the bark without subsequent injury.

AXLEGREASE AND STICKY TREE-BANDING MATERIAL.

A mixture compounded of 1 part of ordinary black axle grease and 2 to 3 parts of sticky tree-banding material recommended by J. R. Horton⁴ was tried on a large number of trees in different localities. This material proved inferior to undiluted sticky material. A few hot, dry days in summer usually caused sufficient hardening of the surface for the ants thereafter to cross at will.

SULPHUR AND STICKY TREE-BANDING MATERIAL.

By far the most satisfactory "tree-sticky" substance tried was a mixture of sulphur and commercial sticky tree-banding material in the following proportions:⁵

Finely pulverized flowers of sulphur.....	parts by weight..	1
Commercial sticky tree-banding material.....	parts by weight..	6

The two materials should be thoroughly mixed until of a uniform consistency. In small quantities this should be done with a wooden paddle, although for large amounts that method is too slow and costly. The most satisfactory method observed by the writers for preparing large batches was a turning machine such as a lathe to which was attached a large corkscrew arrangement. A gallon pail partly filled with the proper proportions of ingredients could be mixed to proper consistency in a few minutes and with little effort. The attempt of one orchardist using a shovel to prepare the mixture in 100-pound lots naturally gave a very unsatisfactory mixture, with the sulphur in lumps, rather than a smooth, consistent mass as desired.

After preliminary experiments had proved that the bands of sulphur and sticky material were superior to all other tree-banding materials used, they were given a very extensive tryout over two seasons under widely differing climatic conditions. The results were variable. In one experiment in which 42 large trees had a heavy 5-inch band applied May 1, only 2 had been crossed by August 14, a period of 3½ months. Three adjacent plots comprising a total of 208 trees, for the most part with limbs 3 to 4 inches in diameter, were treated with bands 2 to 2½ inches wide. From 18 to 34 per cent of these bands were crossed within one month. In

⁴ HORTON, J. R. SOME WEATHERPROOF BANDS FOR USE AGAINST ANTS. *In Calif. State Comm. Hort. Monthly Bul.*, v. 5, no. 11, p. 420. 1916.

⁵ HORTON, J. R. *Op. cit.*

another case of several hundred trees banded with a poorly prepared material, showing granules of free sulphur, a very large proportion of the bands were crossed within a few days following the application. Experience has shown that heavy 4 to 5 inch bands of a mixture of sulphur and sticky banding material thoroughly protected from the sun will keep in good sticky condition during dry weather for a period of 2 to 3 months, or even longer. If exposed to the sun at all, a dry film quickly forms and the ants cross at will. Furthermore, the direct sun causes the material to become very soft and to run down the trunk.

Although there is no particular reason why the addition of sulphur should cause the sticky material to be injurious to the bark of a tree the precaution was taken in all our experimental work to apply first a protective substance. (See fig. 5.) At first 3 to 4 inch bands of oilcloth were applied to tree trunks by means of adhesive tape attached to the upper and lower surfaces, and the tree-banding substance was applied to this band. The difficulty experienced in covering irregular tree trunks with such bands led to search for an innocuous substance that could be painted onto the trunk and the most satisfactory material tried was paraffin. This was first melted and kept at a temperature just above the melting point when applied to the tree trunk. A paint brush proved satisfactory for the work. The paraffin under no circumstances should be at a very high temperature, else it will penetrate deeply into the bark. The requirement is a superficial layer. While the ordinary grade of paraffin recommended for home canning proved satisfactory in thoroughly shaded trees in the coastal districts, in the warm interior valleys, on tree trunks sometimes reached by the sun, they melted on the sunward side and deeply penetrated the bark, causing considerable injury. This necessitated the use of a paraffin with high melting point, one exceeding 130° F. Such paraffins are purchasable of oil-refining companies or dealers in technical supplies. *The caution should be observed, however, that under no circumstances should trees be banded with sulphur and tree-banding sticky material over a paraffin band in situations reached by the direct sun.*

COST.

In 1916 the average cost per tree banded with this mixture was 7 to 8 cents, exclusive of removing the weeds beneath the trees and pruning the branches. At present the cost would approximate 15 cents.

PYRETHRUM AND SODIUM FLUORID.

Sodium fluorid and pyrethrum were used singly or in mixtures and applied to the crotches of trees or on cotton bands around the trunks. (See fig. 6.) The cotton bands usually rid the trees quickly

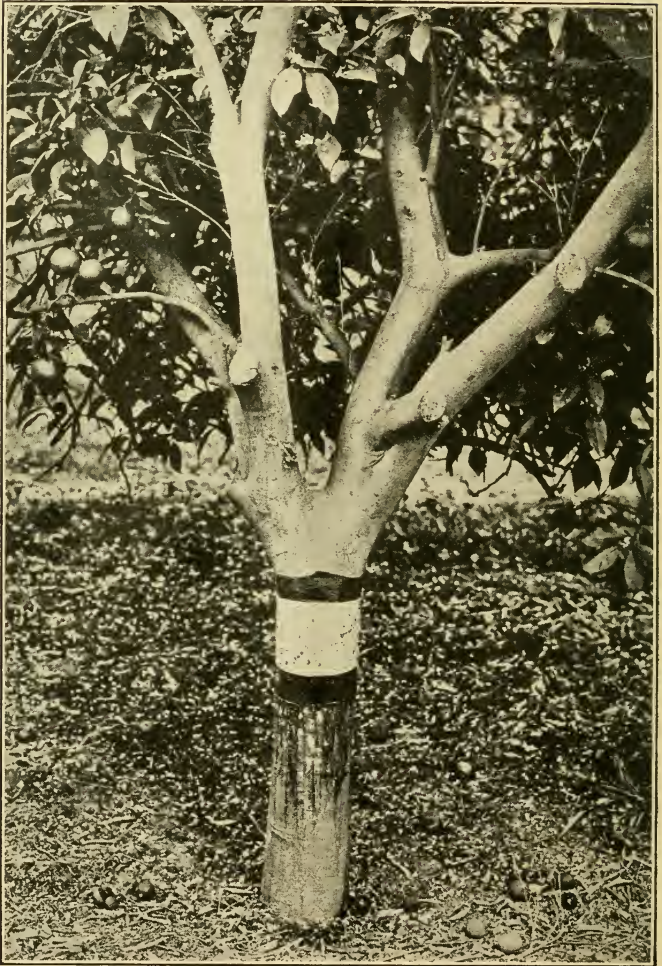


FIG. 5.—Keeping ants off citrus trees. A 5-inch band of sulphur and commercial sticky tree-banding material over a wider coating of paraffin. (Woglum and Neuls.)

of ants but their effectiveness was lost upon exposure to the weather. Once wet these insecticides are valueless. These powders, especially the pyrethrum, singly or in combination with the sodium fluorid, are decidedly repellent to ants and quickly cause death once they come well in contact with their bodies. The fact that their strength is soon lost on exposure to air restricts their usefulness.

The following experiments demonstrate the comparative efficiency of these substances used singly or in combination. Breeding cages containing a large amount of mealybug-infested lemons and potato sprouts were heavily attended by ants which entered in steady streams along the legs. The legs were set in tops of fruit jars containing a small amount of sodium fluorid powder. Ants continued to cross in limited numbers for about one hour before the trails were completely broken up. No dead ants were found.

Pyrethrum powder was sprinkled about the legs of one cage, stopping the trails almost immediately. Dead ants began to pile up in the powder and on the floor about the powder.

A mixture containing pyrethrum 1 part, sodium fluorid 7 parts, and plaster of Paris 2 parts, was dusted about the legs of a breeding cage attended by ants with effects about as satisfactory as with pyrethrum alone.



FIG. 6.—Repellent ant powders: a, Pyrethrum; b, pyrethrum 30 per cent, sodium fluorid 70 per cent. Shaker and blower for applying.

CORROSIVE SUBLIMATE ANT BANDS

Corrosive sublimate has long been known to possess merit as a repellent to ants and this fact has been utilized in protecting materials from these pests. A common method is to soak narrow strips of cloth in a saturated solution of this chemical and use these as barriers. The saturated solution is best prepared by heating about $1\frac{1}{2}$ ounces of corrosive sublimate in an ounce of water until the maximum amount is dissolved. The solution is then allowed to cool, is filtered, and the cotton band or tape is soaked in it for several hours. The tape is then removed, allowed to dry, and is ready for use. This amount of solution is sufficient for from 10 to 12 yards of $\frac{3}{4}$ -inch tape.

Several small nursery trees infested with the cottony-cushion scale, *Icerya purchasi* Maskell, attended by ants, were banded with such tape to determine its effectiveness against the ants, as well as its effects on the trees. The trees were quickly freed of ants and remained so throughout the experiment. The tape, however, soon killed the bark down to the wood and the trees ultimately died.

Fourteen large orange trees were banded with mercuric bichlorid ant tape on September 10, 1915, the tape being wound around the tree several times to form a band several inches wide. The bark was protected from the band by heavy paper. On October 10, one month after the bands were placed, an inspection showed that 5 of the 14 bands had been crossed. These had been rendered ineffective by heavy fogs.

The great danger attendant upon the use of corrosive sublimate, its ineffectiveness when exposed to moisture, and its high cost render this substance generally impractical for repelling ants. It is, however, of special value for protecting apiaries which are seriously troubled by this pest. Newell and Barber,⁶ working in Louisiana, invented a four-legged hive stand from which they were able to keep the ants for many months by winding ant tape about the legs. The writers have tried a similar stand under California conditions with success, even where honey and other substances attractive to ants were profusely scattered over the top. Equally satisfactory with the ant tapes was found a mixture of mercuric bichlorid and shellac which could be applied directly with a brush. A formula adapted from Horton⁷ consists of:

Corrosive sublimate.....	gm...20 or oz... $\frac{3}{4}$.
Alcohol.....	cc...60 or oz...2.
Shellac.....	gm...31 or oz...1.

The corrosive sublimate is first dissolved in the alcohol, then the shellac added, and the mixture shaken until all is dissolved.

FREEING TREES OF ANTS AFTER BANDING.

Freeing trees of ants after banding is an essential part of tree isolation. Heavy infestations of ants at the time of banding will sometimes form a crossing over bands of sticky material from the accumulation of entangled bodies of ants which have attempted to escape from the tree. With corrosive sublimate or ant powders such attempted crossing in no way affects the efficiency of the bands; in fact, on such banded trees ants usually drop off before making an attempted crossing and the trees become free of ants unless colonies are already present in cracks or accumulations of débris in the crotches. Many

⁶ NEWELL, WILMON, and BARBER, T. C. Op. cit., p. 88-91, figs. 11-13, Pl. VII.

⁷ HORTON, J. R. THE ARGENTINE ANT IN RELATION TO CITRUS GROVES. U. S. Dept. Agr., Bul. 647, p. 64. 1918.

large trees support aerial colonies during the warm season and not infrequently colonies have been noted in midwinter.

Several methods of freeing banded trees were tried. The first method was to spray the trunk and main branches with such insecticides as carbolic-acid emulsion or distillate emulsion immediately after banding, the application being made with a compressed-air pump holding 3 gallons. This proved too slow and ineffective, as ants are actively engaged throughout the tree during the day. It was soon observed that the early morning was the proper time to



FIG. 7.—Plumber's torch for applying certain sprays to rid a banded tree of ants.

destroy the ants above the bands, for they are sluggish at the cool temperatures and have the habit of congregating in crotches or in their aerial nests. The compressed-air pump was soon discarded in favor of a plumber's hand torch (fig. 7), in which gasoline or a weak cyanid solution was used as a spray. This in turn gave way to the use of pyrethrum or other ant powders which proved simple of application, economical, and immediately effective. Nests in tree crotches or elsewhere could be quickly freed by a single application, and for this purpose either a small bellows or shaker (fig. 6) proved satisfactory.

SUMMARY OF USE OF REPELLENTS.

Although the writers' experience with banding demonstrated that trees could be kept freed of ants by careful and diligent effort, it was apparent that the constant attention needed for success would not be forthcoming where large acreages were concerned. Furthermore, the method of pruning followed in some orchards produces trees so low that growers seriously object to removal of the large amount of growth necessary for tree isolation except at the trunk. Even after pruning the increasing weight of the fruit weighs down the branches and cultivation frequently breaks small twigs which demand additional attention. Grass and weeds quickly spring up beneath the trees and in contact with a tree leaf furnish a bridge which is invariably discovered by the ants. In fact the ants may find access to a tree by way of a blade of grass which comes in contact with a leaf of the tree momentarily stirred by the wind. In one case a branch of a banded tree rested against a telephone pole and gave a means of reaching the tree. The branch was pruned and the telephone pole banded, yet the infestation persisted. It was finally discovered that the ants crawled along a guide wire to the top of the telephone pole, and thence down to a part where a single leaf momentarily touched the pole as moved by the wind. This was the signal for the persistent little pests quickly to mount the leaf while others moved to the pole.

The glazing of sticky bands where exposed to the sun, the accumulation of falling petals during the blossoming season, the spattering of dust over the bands during rains, or the washing down of dust, leaves, broken twigs, and the materials collected during heavy windstorms, all contribute to render banding with adhesive mixtures impractical over large acreages. In spite of all these drawbacks bands can be made to serve a useful purpose on limited numbers of trees, especially about yards where necessary attention and renewal or respraying can be given. It should be borne in mind, however, that banding merely repels without destroying ants, and destruction is what is actually required.

TRAP NESTING.

The discovery that large boxes filled with decaying vegetable matter would attract ants in numbers in winter induced Newell and Barber to try this plan in infested orange orchards in Louisiana, and their efforts were reputed to have met with great success in reducing the infestations. The trap boxes were subsequently fumigated and the ants destroyed. Horton⁸ also recommended the use of trap nests as by far the best and most practical means of destroying the Argentine ant in the orange groves of Louisiana. The great

⁸ HORTON, J. R. CONTROL OF THE ARGENTINE ANT IN ORANGE GROVES. U. S. Dept. Agr., Farmers' Bul. 928, p. 12-16. 1918.

success attending this method in the Southeast induced the writers to conduct an experiment under the more arid conditions in the Southwest.

A 10-acre orange grove at Upland, Calif., very severely infested with Argentine ants, was selected for the experiment. Five-gallon tin coal-oil cans (9¼ by 9¼ by 13½ inches) were used for traps (see fig. 8), being much cheaper than the wooden boxes, and affording complete protection from rain or winds. One end was cut along three



FIG. 8.—Winter trap nest, consisting of 5-gallon oil cans filled with nesting material, in place at base of tree.

sides and this acted as a flap over the entrance of the can, protecting it from beating rains. Three hundred and fifty cans were used, being divided into seven lots of 50, each lot containing a different filler. These were respectively green grass and dirt, green grass, green alfalfa, dry straw, wet straw, moist dirt, dirt, and leaf mulch. The cans were placed on a side, close up to the base of the tree. Approximately 3 of the 10 acres were reserved as a check, the remaining 7 being covered with ant traps, one to each tree on about 3 acres and one to every other tree on the remainder. These were placed December 1, 1917.

An inspection February 7, 1918, showed that some ants had colonized in the cans, but in the absence of heavy rains the ants were continuing largely in their ground colonies. A final inspection March 18, 1918, showed that only 41 per cent of the cans contained nests, and these were for the most part small. Many colonies were found in the ground beneath the cans or even at the base of the trees near the cans; in fact, in all cases the preponderance of ants in the orchard appeared to be outside the cans. The cans were fumigated with carbon disulphid immediately following the final inspection. An inspection of the entire grove in May showed the ants as prevalent in the part over which ant traps were distributed as in the check plot, thus demonstrating the futility of ant control in California by the trap-nest method recommended for Louisiana.

A second experiment in an adjacent grove with 50 trap boxes during the same winter gave no better results.

The success of trap nesting, as pointed out by Newell and Barber, depends upon rainy weather. The winter of 1917-18 was a warm and open one with light rains, and this resulted in ants being more or less active in southern California throughout the season. It is very probable that in a colder winter with heavy rains trap nests would be more successful. Even under the most ideal conditions for trap nesting, however, this method would be less effective and more costly than the poisoned-sirup method later taken up in this publication.

POISONED SIRUPS.

Eradication is the ideal to be sought with any pest and particularly does this apply to the Argentine ant. Once the ant is eliminated from a grove, future effort can be restricted to protecting the borders from invasion from neighboring property. The most effective method of eradication tried in California has been the use of a poisoned sirup, which is eaten by the ants. For the most part arsenic in some form constitutes the toxic substance of such a poison, although a few nonarsenicals have been used.

In all orchard work small containers of tin or paraffined paper were used, partly filled with sirup and hung one to a tree, the ants entering through small holes in the sides.

CHLORAL HYDRATE.

Chloral hydrate was recommended by Horton⁹ as the best poison for orchard use. It is prepared as follows:

Make a sirup by stirring 8 pounds of granulated sugar in one-half gallon of cold water until dissolved, making 1½ gallons of sirup. Then add 4½ ounces of chloral-

⁹ HORTON, J. R. CONTROL OF THE ARGENTINE ANT IN ORANGE GROVES. U. S. Dept. Agr., Farmers' Bul. 928, p. 19. 1918.

hydrate crystals, previously dissolved in a small quantity of water, and about one-half pound of strained honey.

On July 22, 1918, an orchard experiment was started in which 2-ounce spice tins about one-third filled with chloral-hydrate sirup according to the foregoing formula were hung on 48 trees attended by heavy trails of ants. The ants fed on this sirup greedily when first distributed and continued feeding freely throughout the duration of the experiment, which was five months. The sirup started crystallizing about one month after being distributed and within six weeks most of the containers were partly filled with large crystals resembling rock candy. Although the sirup proved attractive, it did not appear to reduce the numbers of ants more rapidly than they bred, for ants were almost as numerous at the completion of the experiment as at the beginning. The tendency of this sirup to crystallize and its only partial action against ants show it to be not fully satisfactory as a poison.

ARSENICAL POISONS.

Arsenic in large quantities acts as a repellent to ants and its earliest use against the Argentine species was based on this action. Woodworth, experimenting later with this insect in the San Francisco Bay region of California, obtained success in control by the use of an unboiled sweetened poisoned sirup containing about one-fourth of 1 per cent of sodium arsenite.

In 1916 E. R. Barber¹⁰ published the results of his efforts against the ant in Louisiana with an improved arsenical sirup and showed for the first time that eradication was possible over extensive areas. This system immediately appealed to the senior writer as offering a more practical solution of the ant problem in California than banding, which he had previously been using, and accordingly an experiment in controlling the ants about the laboratory was started in October, 1916, and met with marked success. In December, 1916, an orchardist, who had observed the effectiveness of the system installed on the laboratory grounds, attempted control on his property by this method. This was the first control attempted in southern California in a citrus orchard. Others were thereupon induced to adopt the methods which Mr. Barber had proved eminently successful in Louisiana, and at the same time the writers started an investigation of the use of this poison under California conditions. This led to experimenting with various other formulas containing arsenic as the basic poison and the ultimate development of a formula thoroughly satisfactory under California conditions.

¹⁰ BARBER, ERNEST R. THE ARGENTINE ANT: DISTRIBUTION AND CONTROL IN THE UNITED STATES. U. S. Dept. Agr., Bul. 377. 23 p., 5 fig. 1916.

ORIGINAL BARBER FORMULA.

Orchard A. The owner of a 10-acre orchard of large Valencia and naval orange trees located at Alhambra in a district overrun with the Argentine ant was induced to attempt control by the use of the poisoned sirup which had proved so successful in Louisiana. This work was done under contract and the poison prepared according to the original Barber formula as follows:

Granulated sugar.....	pounds..	15
Tartaric acid (crystallized).....	ounce...	$\frac{1}{4}$
Sodium arsenite C. P.....	do....	$\frac{3}{4}$
Honey.....	pounds..	$1\frac{1}{2}$
Water.....	pints..	8

A special 1-pound paraffined paper sack punched with a few small holes and containing about an ounce of sirup and a 1-inch cube of sponge was attached to each tree, either on the trunk or one of the main branches. The orchard was in a state of clean cultivation with no grass or weeds beneath the trees, and in most cases the lower limbs were entirely free of the ground, so that the trunk formed the only means of access to the tree for the ants. The distribution of filled containers was made on May 14-15, 1917. No inspection was made at the time of sirup distribution, although during the previous autumn trails of ants were present on every tree, and a careful examination in April showed heavy streams of ants on trees in all parts of the orchard.

Some of the paper bags lost their contents soon after distribution and these were replaced in the latter part of June. The sirup thickened rapidly during the summer and by the first of August, or probably two months after the experiment was started, the contents of many bags had commenced to crystallize or solidify. When this stage was reached, it was noted that the sirup no longer proved so attractive to ants. A few bags were refilled in August, and in September fresh sirup was placed in all containers.

After the sirup was distributed frequent inspections of this orchard were made throughout the season of ant activity and notes taken on the progress of the control and eradication. These results were most encouraging and showed conclusively not only that orchard control of the ant was possible, but that the ant could be eradicated by persistent effort.

The experiment began on May 14, with most of the trees in the orchard heavily attended by trails of ants; by May 22, or within a week's time, these had been reduced to only 26 per cent with trails; and within two weeks to 11 per cent. By July 19, or two months after the poison was distributed, the ants had either been entirely destroyed or reduced to within the limits of control on 98 per cent

of the trees in the orchard. With the approach of the middle of August the ants were practically controlled throughout the orchard.

Progress (fig. 9) is naturally slower from the standpoint of eradication than of control. For the first month eradication of ants from trees was constant and rapid, 52 per cent of the entire orchard being freed within this time. Then eradication slackened and for the succeeding 6 weeks made no noticeable gains. By the middle of August an increased number of trees were free of ants and this continued until by the middle of November ants had been eradicated

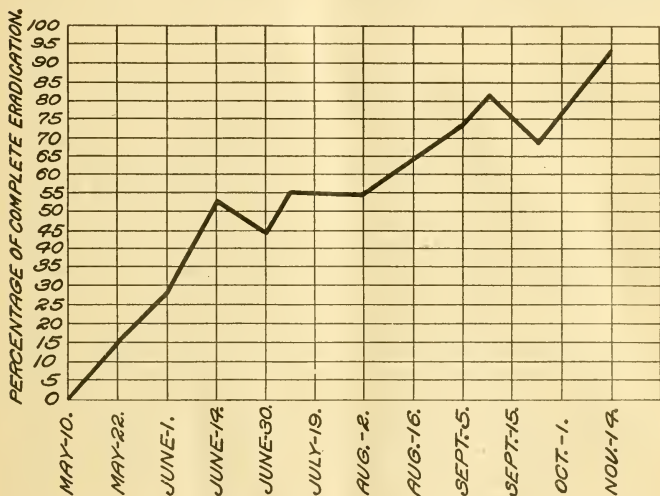


FIG. 9.—Progress of ant eradication on a 10-acre citrus orchard.

from 92 per cent of the trees, those remaining being mostly marginal and attended by a few stragglers from adjacent property.

It should be noted in presenting the marked success of this experiment that the trees were quite free of scales, although a few mealybugs were present. Therefore the food supply was not particularly abundant. Likewise worthy of note is the fact that this orchard had been severely infested with *Pseudococcus citri* for four years prior to ant control but since then this pest has been effectively controlled by its natural enemies.

TABLE 1.—*Effectiveness of Barber poisoned sirup in the control of the Argentine ant in a citrus orchard.*

	Dates of inspections.											
	May 22.	June 1.	June 14.	June 30.	July 19.	Aug. 2.	Aug. 16.	Sept. 5.	Sept. 15.	Oct. 1.	Nov. 14.	
	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	
Free of ants.....	15	28	52	44	55	54	63	72	81	69	92	
Trails of ants.....	26	11	11	4	2	1	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	0	
Few straggling ants.....	59	61	37	52	43	45	36	27	19	30	8	
Either free of ants or with few stragglers only.....	74	89	89	96	98	99	99	99	100	99	100	

Orchard B, located at Upland, Calif., consisted of 6 acres of Valencias and 4 acres of naval oranges, with a total of 674 trees. They were very large, being about 25 years old, and quite severely infested with the *citrophilus* mealybug. The lower limbs which rested on the ground were trimmed up, thereby forcing the ants to ascend the trunks. The orchard was in a clean state of cultivation with no vegetation growing beneath the trees. The ant sirup was prepared according to the original Barber formula and put out in 1-pound paraffined paper bags, one to each tree as described in orchard A. The distribution of the sirup was completed October 5, 1917. A careful inspection was made from time to time to note the stability of the sirup and its effectiveness against the ants. Some crystallization appeared within 6 weeks, and by the end of the second month practically all had hardened. The ants fed heavily on the sirup before crystallization took place and their numbers became greatly reduced during the autumn months. Although prior to the sirup distribution only 5 of the 674 trees were free of ants, all the remainder being attended by trails of ants, many having two or even three trails along the trunk, these trails became weaker and weaker and were almost broken by the time the sirup began to crystallize.

There was slight ant activity throughout the winter, due to the open season. On March 3 and 4, 1918, an inspection of the orchard showed above 99 per cent of the trees entirely free of ants, only 3 of the 674 trees being infested. By April 9 ants had invaded the orchard from severely infested adjoining territory, so that 26 trees were infested. Fresh sirup was distributed on these trees at this time, and on June 17 on other marginal infested trees. By June 29 ants had been eradicated from 672 of the 674 trees in the orchard, and the experiment stood as a determination of the efficiency of the poisoned-sirup method in orchard eradication of ants.

Cost.—The cost of ant eradication in these 10 acres, including the materials, labor in preparation, and distribution of 674 containers in October, 26 in April, and 32 in June (a total of 732), amounted to \$19.03, or 2.6 cents per tree.

Crystallization.—The sirup prepared with the formula used in orchards A and B commenced to thicken in from two to four weeks after its distribution in the orchard and crystallization started in from six weeks to two months. Sirup distributed in the dry cold weather of late fall was observed to crystallize in some cases within a month. The sirup proved less attractive to ants as it thickened, and crystallized sirup was little attended. Although the Barber formula proved very effective against the ants under conditions where heavy feeding followed the initial distribution, and control was really effected during the period of normal stability of the sirup, as was the case in orchards A and B, weather conditions and normal food supply of the ants frequently were such that feeding was slight during the early weeks of distribution. If in such cases the sirup became crystallized within a month or six weeks following the distribution its effectiveness against the ants was greatly reduced.

The situation is well presented by the comparison of ant control in a 10-acre orchard adjacent to orchard B, at Upland. The orchard consisted of 676 trees, 76 of which were reserved for control by another system. Ant control by the same sirup as used in orchard B was started in the remaining 600 trees, which were largely navel oranges with ant infestation practically identical with that in orchard B. The distribution took place during the first part of November, or fully a month later than in orchard B, and the sirup crystallized within a month after being put out. Although above 99 per cent of the trees in orchard B were free of ants on March 24, 1918, in this latter orchard only 65 per cent were in this condition. The difference in control is attributable to a shorter period of sirup supply. This crystallization of sirup led to experiments in an effort to secure a sirup of greater stability and possibly more attractive to the ants.

MODIFIED BARBER FORMULA I.

Observations indicated that sirup which had become diluted by rain entering the container was more stable than the more concentrated sirup. This led to the use of a modified formula in which the sugar was reduced from 15 pounds to 12 and the honey increased by one-half pound to compensate for the reduced sweetness. Experiments with this sirup during 1918 proved it to be as attractive to ants as the original formula and its stability was greatly increased, for during the summer it remained without crystallizing for periods up to four months. This sirup was used over a great acreage during 1918 with marked success. With the approach of cold weather it was found that this sirup would crystallize, though much more slowly than the thicker sirup.

Unboiled sirup.—An experiment was started on 50 trees in which the modified Barber formula was prepared without boiling, the sugar

being dissolved in lukewarm water, to which the dissolved arsenic and honey were then added. No tartaric acid was used, for an alkaline sirup, which might prove more attractive to ants, was desired. During the first week the ants fed more freely on the unboiled sirup than on the boiled sirup in an adjacent plot, and at the end of the first month both sirups proved equally attractive. The unboiled sirup then started to turn dark and decompose, after which its attractiveness to ants was greatly decreased. The boiled sirup, however, was in perfect condition at the end of the month and its attractiveness continued. This plainly shows that the instability of an unboiled sirup renders it less useful than the boiled sirup.

Saccharin.—The shortage of sugar in 1918 led to experiments with substitutes, and of these saccharin, supposedly 600 times sweeter than sugar, was one of the first tried. A formula was prepared using three-fourths of an ounce of saccharin, 2 pounds of honey, and three-fourths of an ounce of sodium arsenite to 2 gallons of water. Three-fourths of an ounce of saccharin is equivalent to 28 pounds of sugar, and at this rate the sweetness of the sirup was approximately twice that of the regular Barber formula. This sirup was lightly attended by ants during the first few days following its distribution, but thereafter proved repellent. Other formulas were made containing decreased amounts of saccharin, but in all cases the sirup proved unattractive to the ants.

Glucose.—Glucose was used in several different formulas as a substitute for sugar. In no case did it prove as attractive or effective as the original or modified Barber formulas.

MODIFIED BARBER FORMULA AND CHLORAL HYDRATE.

A sugar sirup with chloral hydrate as the poison proved highly attractive to ants but did not possess the required killing properties. It was thought, therefore, that chloral hydrate added to the modified arsenical formula might increase the attractiveness of the latter to ants and result in their very rapid eradication. Accordingly, 3 ounces of chloral hydrate in solution was added to 1 gallon of the arsenical sirup and the mixture distributed in containers on ant-infested trees. The ants attended the cans slightly at first, but the sirup proved repellent. Other formulas with greatly reduced chloral hydrate proved equally repellent.

FINAL FORMULA.

The thickening of the sirup in modified Formula I during the summer and its frequent crystallization after protracted exposure to cold weather during the winter led to the preparation of a still more dilute ant sirup, in which 11 pints of water were used instead of 8 pints as previously. This new sirup was first prepared during the spring of

1918, and has since been used on more than 2,000 acres of citrus. It is of thin consistency and greater stability than Formula I. It has proved very attractive to ants and has been highly effective in control and eradication. It was discovered, however, that fermentation of this more dilute sirup sometimes occurred, especially in the damper sections near the coast. This was corrected by the use of benzoate of soda at the rate of 0.1 per cent.

Preparation of final and most satisfactory formula.—The final formula was prepared as follows:

		Cost.
Water.....	11 pints.....	\$0.000
Tartaric acid (crystallized).....	7 grams.....	.016
Benzoate of soda.....	9 grams.....	.029
Granulated sugar.....	12 pounds....	3.00
Honey, strained.....	2 pounds.....	.77
Sodium arsenite, C. P.....	$\frac{3}{4}$ ounce.....	.047

Total sirup, 2½ gallons. Cost per gallon, \$1.54.¹¹

Put 10 pints of water in a clean vessel over a low fire. When tepid add tartaric acid, then benzoate of soda, and then the sugar, slowly, while stirring to prevent burning. Measure the depth of the liquid with a stick. Slowly bring it to a boil and allow it to simmer for from 30 to 40 minutes. Remove from the stove and add water to compensate for evaporation. Stir in the honey before the mixture cools. Then add sodium arsenite which has been dissolved in 1 pint of hot water and partially cooled before being poured into the sirup. Stir thoroughly.

It is necessary that great care be exercised in the selection of the materials used, as well as in the preparation of the sirup. Either cane or beet sugar may be used. The sodium arsenite should be chemically pure. The honey should be strained and free of comb. The sodium arsenite preferably should be dissolved in distilled water to avoid the precipitation which sometimes occurs if very hard water is used. Vessels should be thoroughly cleaned before being used for the preparation of ant sirup, and it is desirable that they be used for this purpose only. Oils and various chemicals are distasteful or repellent to ants, and sirup which acquires a flavor of such substances from the container in which it is prepared or stored may be unattended by the ants. The stability of the sirup depends much upon the way it is boiled. If brought to a boil within a few minutes and boiled vigorously for 30 minutes the stability appears to be much less than if brought to a boil very slowly and then merely allowed to simmer for 30 or 40 minutes. Where several times the amount given in the formula is made in a large vessel the sirup appears to "stand up" best. This seems due to the fact that the sirup does not come to a boil for an hour or longer, and this probably results in greater inversion. The sirup should be used when fresh. Clean glass bottles are best if the sirup is to be stored.

¹¹ With sugar at present prices (about 10 cents a pound) the cost would be only about 82 cents a gallon.

CONTAINERS.

BAGS.

One type of container extensively used was a $\frac{1}{4}$ -pound paraffined paper bag (fig. 10.) Well-made paper bags were purchased in large quantities, punched about 2 inches above the bottom with four holes small enough to exclude honeybees, and dipped in molten paraffin of



FIG. 10.—A paraffined paper bag in place on tree.

a melting point above 124° F. Paraffin, being highly inflammable, should be removed from the stove during the dipping. The top of the bag is held with a pair of curved forceps or pliers, the bag completely submerged in the paraffin, momentarily drained, and stood top upward on a greased board or tin. This allows the residue paraffin to settle well into the bottom, the part where leakage is most apt to occur. Bags were found to be quite satisfactory and the least

expensive of all containers. They have, however, certain drawbacks. They are prone to leak and wherever the arsenical sirup drips on the bark of a tree injury follows. Therefore it has been found advisable to hang paper sacks to the trunk or main branches so that no sirup will drip on the tree. During the rainy season the unprotected paraffined sacks as used in California collect water and do not stand up well.



FIG. 11.—A paraffined spice tin on tree trunk.

Ants, however, are for the most part inactive at that time, so control is seldom necessary during the winter. One great advantage of paper bags is that feeding by the ants or crystallization of sirup is quickly detected without removal and opening. Paraffined drinking cups or other paraffined containers on the market could be used in orchards for holding ant sirup.

CANS.

Sixteen-ounce round baking-powder tins recommended by Barber were tried in one orchard but proved too large and cumbersome. Several hundred 4 and 8 ounce tins of the same shape were used in experimental plots. These proved more satisfactory. In canvassing the market for different types of tins available in quantity at a reasonable price it was found that the 4-ounce oblong spice tin with plain cover (fig. 11) met the requirements most closely. Such tins are crimped without solderings and are not water-tight at the seams. It was found that dipping these cans in paraffin of high melting point covered both the inside and outside with a thin, almost invisible

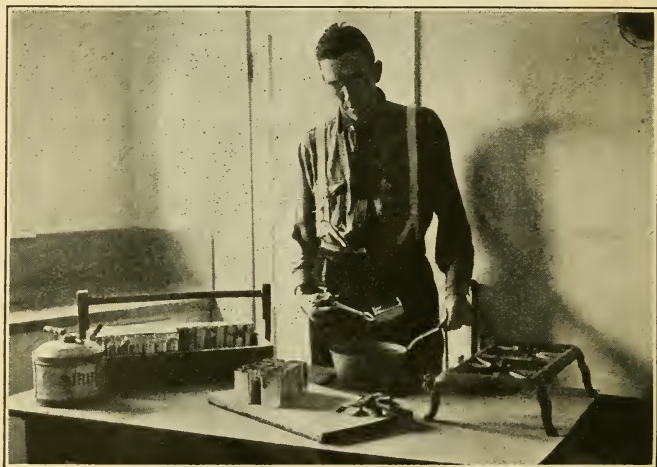


FIG. 12.—Method of paraffining spice tins for use in the field.

coating, prevented leaking, and rendered them rust-resistant. (Fig. 12.) One small hole was punched in a side about 1 inch below the top and the can hung by it on the tree over a 2d. finishing nail. These cans have proved the most satisfactory of all containers. They lie close to the trunks of the trees and are not moved by either wind or rain. When the ants are sluggish, as they are in cold weather, not uncommonly they cluster beneath the can and this doubtless increases their feeding.

GROUND TRAPS.

In control work about houses, especially where there are large lawns, and also in conservatories where water is freely used, water-tight round cans are advantageous. These are set in the ground along

the main runways of the ants. A small baking-powder can with friction cover indented in two or three places immediately beneath the cover to allow passage of ants would prove satisfactory. Such a can is being used in Louisiana. A very successful lawn trap used in California consists of a pimienta can protected by a special cover attached to a 6-inch stake. (Fig. 13.) A hole is made in the grass large enough for the can. The stick is then set into the ground until the cover fits firmly over the can. When these covers are painted foliage-green and sunk even with the grass they are inconspicuous. The lawn can be mowed or watered without destroying the sirup or container.

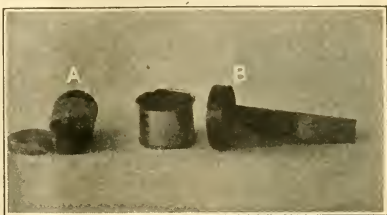


FIG. 13.—Types of ground traps: a, A small baking-powder tin with the edge bent to permit passage of ants; b, a special ground trap used in California for control about residences.

FILLING AND DISTRIBUTING CONTAINERS

It has been found most practical to fill the containers in the field. The cans or bags are prepared beforehand and taken into the orchard.

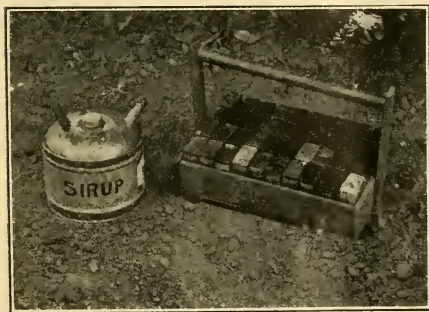


FIG. 14.—A convenient type of tray for field distribution of poison containers, and a 1-gallon can for holding poisoned sirup.

These are arranged on trays as shown in figure 14. A gallon can with a long spout is handy for filling. In each container three-fourths to one inch of sirup is used and this in reality averages about $1\frac{1}{2}$ ounces. At first small cubes of sponge were used in each can or bag to increase the feeding surface. It was soon discovered that the sponges hastened evaporation and thick-

ening of the sirup and were thus a disadvantage rather than an asset. A very satisfactory substitute for the sponge was found in excelsior and four or five clean strands about a foot long were folded very loosely in the can or preferably suspended from the top, as shown in figure 15. Under no circumstances should a large, heavy, compact wad of excelsior be used. The advantage of the loose strands is that they furnish an attractive runway for the ants, reduce the likelihood of their

becoming entangled in the sirup, and at the same time increase the feeding area. When folded into a compact mass excelsior is unsatisfactory and tends to obstruct the free passage of ants, and furthermore absorbs much of the sirup unless the can is well filled. Excelsior has entirely displaced sponges in California.



FIG. 15.—A spice tin with front removed to show amount and arrangement of excelsior.

After the spice tins or bags are filled, the tops are put on or the upper part of the bag folded, and they are then ready for attachment to the tree. (Fig. 11.) The bags are tacked as shown in figure 10. The cans are hung on a small finishing nail which is first driven into the tree. The containers should be on either the trunk or main branches on the shady side of the tree.

REFILLING.

The writers have practiced and advocate monthly inspections. A tray of filled containers should be carried along and where an empty, missing, or crystallized container is found it can be replaced. If crystallization is general all containers should be removed. Fresh sirup should never be poured onto that crystallized, as it has been found that normal sirup mixed with crystallized sirup quickly hardens. Where bags are used they can be discarded for new ones. Crystallized sirup can be easily removed from cans by heating to boiling. (Fig. 16.) The cans should be repara-fined.

NUMBER OF CONTAINERS.

A container should be attached to each tree in orchards over run with ants. The ants colonize around the base of the trees where the food supply is plentiful, and in clean-cultivated orchards, such as are common in California, and are seldom found between the rows of trees. When food becomes scarce, movement from one tree to another is more common. One striking case of the restricted movement



FIG. 16.—Cleaning crystallized sirup from container. Cans are arranged in trays and boiled in water, after which the contents are quickly removed by inverting the trays.

One striking case of the restricted movement

of ants in well-cultivated orchards was observed in an orchard during the spring of 1920. One row of trees near the center of the orchard was missed at the time of sirup distribution, and the first inspection showed the ants almost totally eradicated throughout the orchard with the exception of this one row, which continued to be heavily infested. During experimental work groups of trees in one side of an orchard have had the ants controlled through sirup distribution although the rows bordering these trees were little influenced. Orchards in which only part of the trees are attended by ants need sirup containers only on the infested trees. In California the plantings are for the most part from 70 to 100 trees to the acre.

COMPARATIVE COST OF TINS AND PARAFFINED BAGS.

The cost of ant sirup fluctuated greatly during the period of experimental work, 1917 to 1920, largely because of the changing price of sugar and honey. The cost of materials for each gallon of sirup in 1917 was \$0.61 compared to \$1.54 in 1920. The cost of the 2-ounce flat spice tins increased about 20 per cent, while paper bags increased over 35 per cent in price. The labor cost also materially increased. The following comparison is based on 1920 prices:

TABLE 2.—*Showing the comparative cost of poisoning ants when using tins and when using paraffined bags, season of 1920.*

Two-ounce flat spice tins.		One-fourth-pound paraffined bags.	
Ant sirup for 100 cans ¹	\$1. 83	Ant sirup for 100 bags ¹	\$1. 83
100 2-ounce spice tins.....	1. 75	100 ¼-pound bags.....	. 15
1 pound paraffin.....	. 25	1 pound paraffin.....	. 25
100 2d. finishing nails.....	. 015	100 6-ounce tacks.....	. 025
LABOR. ²		LABOR. ²	
Punching and dipping 100 cans.....	1½ hours.	Punching and dipping 100 bags.....	1½ hours.
Filling and capping 100 cans.....	¼ hour.	Filling and closing 100 bags.....	¼ hour.
Distributing.....	1 hour.	Distributing.....	1 hour.
At \$0.39.....	3 hours. 1. 17	At \$0.39.....	2¾ hours. 1. 07
Total.....	5. 015	Total.....	3. 325
Total cost per can.....	. 05	Total cost per bag.....	. 03½

¹ Based on 84 cans to the gallon at \$1.54 per gallon.

² This does not include time spent in preparing sirup.

INFLUENCE OF CONTAINERS ON FEEDING.

Although both paraffined paper sacks and tin cans have been used by the writers for approximately three years, no difference in feeding or rapidity of control attributable to the type of container was observed. It has been stated by some experienced in ant control that greater feeding and more rapid control are effected by the use of paraffined paper bags. An experiment to determine this point was started in 1920 and the results are presented herewith: Sirup

was put out on 46 trees in $\frac{1}{4}$ -pound paraffined bags and on 46 trees in 2-ounce paraffined spice tins. Frequent inspections were made of the feeding habits and careful attention paid to any apparent preference for either type of container. The experiment was conducted for two months and percentages figured showing the relative feeding habits. An average of 63 per cent of the bags were attended during the period, and an average of 62 per cent of the cans were fed upon. The ants showed no apparent preference for one type of container over the other. It has been observed that evaporation is more rapid in the bags than in the cans, hastening thickening of the sirup.

FACTORS INFLUENCING CONTROL.

The control of the Argentine ant under California conditions is very variable. In some cases control has been effected within one to two months and occasionally eradication within a like period. In others not even a noticeable reduction of ants has been accomplished within a much longer period. Inspection of containers in certain orchards has shown an occasional ant to feed for several weeks after distribution, while in other cases containers would be swarming with ants within a few hours after the sirup was placed within reach. As a general rule, however, the feeding is heaviest for the first few days when the sirup is fresh; after this the attractiveness is somewhat reduced.

WEATHER.

The weather, especially the temperature, appears to influence feeding greatly. During the hot summer months an arsenical sirup is less attractive than at any other time of the year, and control is slow, frequently unsatisfactory. The ants at this period are exceedingly active, and heavy streams have been known to pass up and down the trunk for weeks at a time, in some cases even right up against the container, without being influenced in the least by the proximity of the sirup. This extreme indifference to sirup is the exception rather than the rule. The maximum temperature at which ants actually slacken or stop activity has never been noted, but the senior writer has observed ants moving freely along the tree trunks at a temperature of 117° F., a degree of heat that proved destructive to many Diptera and Neuroptera. The writers have observed that the movement of ants becomes sluggish as the temperature of 50° F. is approached, and it is during these periods of low temperature that the sirup appears to prove most effective. The tendency of the ants is to cluster close together during the cool mornings in spring and autumn, especially in and about the crotch of the tree. If containers of sirup are present they prove a center of attraction and are frequently attended in large numbers.

FOOD SUPPLY.

Trees severely infested with mealybugs or other honeydew-exuding insects offer a favorable food supply for the Argentine ant. Control on such trees is difficult at any time of the year and usually not to be accomplished during the summer merely by the distribution of sirup, for the ants prefer their natural food to that furnished artificially. The only way to control the ants under such conditions is to remove the insects furnishing the natural food supply, prevent access of the ants to these insects, or else await the autumn or spring when the natural food becomes much reduced and the cold weather promotes feeding on the poisoned sirup. As an illustration of this condition the case of an orchard at Sierra Madre might be mentioned. On June 1, 100 bags of ant poison were distributed in one corner of the orchard, which at the time contained a few mealybugs. Within two months the ants on these trees had been brought under control. On August 1 poison bags were distributed throughout the rest (about 10 acres) of this ant-infested orchard, which was then severely infested with mealybugs. An inspection on October 19 showed no noticeable reduction of ants throughout that part covered by ant sirup in August. The infestation of mealybugs also continued to be severe. With the approach of cold weather and reduction of the numbers of mealybugs the ants fed greedily on the sirup, and by the following spring were practically under control.

On April 26, 1918, ant sirup was placed on 68 large orange trees at Pasadena severely infested with mealybugs. Forty-two of these trees were banded above the sirup cans to prevent the ants reaching the mealybugs, and the remaining 24 were left unbanded. An inspection on April 30 showed large numbers of ants attending the sirup on the banded trees, but not a single can on the unbanded trees was sought by the ants. The second plot was ultimately banded to compel feeding and accomplish control.

During the blossoming period ants are attracted to the nectar within the flowers and control is sometimes difficult, especially during a period of warm weather.

Thus, any attempt at control should give due consideration to the natural food supply of the pest.

Excellent results in complete ant eradication have been obtained in orchards heavily infested with the soft-brown scale and the black scale by following up the usual fall fumigation practice with ant control.

SEASON FOR CONTROL.

The spring and autumn, because of the temperature and food supply, are the periods when control or eradication is most quickly effected in southern California. When the ants break up their

winter colonies in the spring, their instinct to multiply leads to an aggressive search for food at a time when the supply is scarce. Consequently, they feed ravenously at this time on ant sirup when offered. It is also during the spring and autumn that the night temperature approaches 50° F., which reduces ant activity, causes the ants to congregate in or about tree crotches of the main limbs, and greatly increases feeding, particularly in the case of trees infested with honeydew-producing insects. During the hot summer months, when the temperature seldom drops to 50° F., ants are active both night and day, and where other food is available they are not greatly attracted by the poisoned sirup.

This temperature influence, and the further important consideration that scale control by fumigation is confined largely to the autumn months, make the fall and spring desirable periods for poisoning the Argentine ant. The writers recommend that control be started between the time ants first appear in the spring and July 1, or from the last of September until congregation into winter colonies takes place. The time of the appearance of ants in the spring varies from year to year, as well as from locality to locality. In 1916 ant activity started the last week in February, whereas in 1920 it was about the middle of April before the winter colonies began to break up. With the approach of cold weather, which normally sets in during December, ants disappear from the trees, although in a very open winter, as that of 1917, complete winter colonizing does not occur.

REAPPEARANCE OF OTHER ANTS FOLLOWING CONTROL OF THE ARGENTINE SPECIES.

It has been stated by Newell that the Argentine ant will not tolerate the presence of other species of ants within its domains. In southern California the commonest species of ant in citrus groves not entirely overrun with the Argentine ant is *Prenolepis imparis* Say. *Formica cinerea* Mayr, var. *pilicornis* Emery ranks second, and *Tapinoma sessile* Say, *Dorymyrmex pyramicus* Roger, and *Cremastogaster lineolata* Say, var. *californica* Emery are of lesser importance. Orchards long infested with Argentine ants are entirely freed of these other species. The reappearance of *Prenolepis imparis* closely following the eradication of the Argentine ant has often been noted, particularly during the autumn and early winter months. One striking instance occurred in 1918 at Pasadena, where ant control was started in April on 258 trees, 4 of which were frequented with *Prenolepis*. These four infestations of *Prenolepis* were eradicated, and the Argentines on the other trees were brought under control during the summer and totally eradicated during the month of November, with the exception of a few trees in one corner. On October 17 *Prenolepis* reappeared on 1 marginal tree and by Novem-

ber 15 had spread to 41. By the middle of December this ant had established colonies throughout the orchard, with the exception of the corner where the Argentine species still maintained a foothold. Several instances of like incursions, but in lesser degree, occurred in orchards at Upland in 1918 and at Alhambra in 1919.

RELATION OF BREEDING TO CONTROL.

The most rapid and conspicuous increase in numbers of ants is during the months of July, August, and September, and this is accounted for by the high mean temperatures prevailing during that period and the abundance of available food. High temperatures stimulate the queen to maximum egg production, and the life cycle of workers from egg to maturity under these most favorable weather conditions approaches four to five weeks, instead of two to four months, as during the coldest weather. Since the Argentine ant has been observed to slacken activity at temperatures below 60° F., it is apparent that during the spring and autumn not only does the egg production become greatly reduced, but the period of development is lengthened. Therefore, poison distributed during the spring and autumn should prove most effective.

During the hot summer months when all stages are present and the development is so swift the rapid destruction of all workers present at the time of sirup distribution would not clean up the infestation because additional workers would be daily emerging from the pupæ and these could care for the undeveloped larvæ. Eradication of the young during the summer by poisoning of workers is less likely at this time than during the period of slow development.

CONTROL ON MARGINAL TREES.

Ant eradication has been most difficult on the outside rows of orchards, particularly so when bordered by ditches or strips of uncultivated land. In clean-cultivated orchards, as stated elsewhere in this bulletin, there is little movement between trees, yet the marginal rows are commonly attended by ants breeding in the strips of bordering ground. If this adjacent territory is heavily colonized by ants, the latter will be attracted by sirup on these trees. The greatest difficulty has been experienced at times in eradicating ants from these trees, and ants have been eradicated from entire large orchards with the exception of outside trees. The difference in rapidity of eradication between the marginal two rows of trees and the rest of a 10-acre orchard by the sirup method is shown in figure 17. Orchards from which ants have been entirely eradicated one year have been known to have the outside two to three rows reinfested the following year from adjacent ant-sustaining territory. As a matter of precaution it is sometimes advisable to keep containers of sirup on the outside row

of trees even after ants have been eradicated from an orchard. Such action, if long continued, ultimately will result in reduction or control of the ants in the immediately adjoining strip of land and will act as a protection to the rest of the orchard. Particularly necessary is it to keep up the fight on house-lot property. The writers have totally eradicated ants from small city properties only to have incursions a short time later from the outside.

CLEAN CULTURE.

Ant eradication by the sirup method is difficult in uncultivated orchards or in orchards with rank vegetation beneath the trees. (Fig. 18.) Weeds and grass harbor plant-lice, scales, and other in-

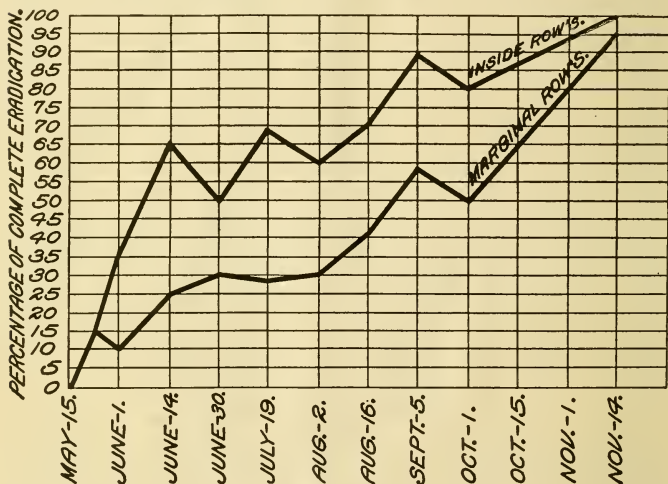


FIG. 17.—Comparative progress of ant eradication on marginal and inside rows of a 10-acre citrus orchard.

sects which furnish honeydew and distract the ants from the sirup. Such growth in contact with the branches offers avenues of travel distant from the poison. Clean culture should be practiced and, where possible, the lower branches pruned to prevent access to the tree except by the trunk. (Fig. 19.)

CONTROL ON HOUSE LOTS OR ABOUT BUILDINGS.

The control of ants on house lots or about buildings requires greater attention than does orchard work and furthermore is slower. Ground traps are advantageous in addition to the regular field containers. In order to effect rapid reduction of the pest, liberal distribution of containers has been found advisable. It has been the custom of the



FIG. 18.—A citrus orchard in which clean culture is not practiced. It is difficult to obtain ant control by the poisoned-sirup method on such property.



FIG. 19.—Citrus orchard showing clean cultivation, a condition necessary if rapid ant control by the use of the poisoned sirup is to be secured.

writers to hang a container on each tree or shrub about the property and to place several about the house along the foundation where trails of ants are found. Where ant-frequented property adjoins, it is well to distribute containers at the margin. They can be tacked in protected places on fences or to hedges. Ground traps should be placed

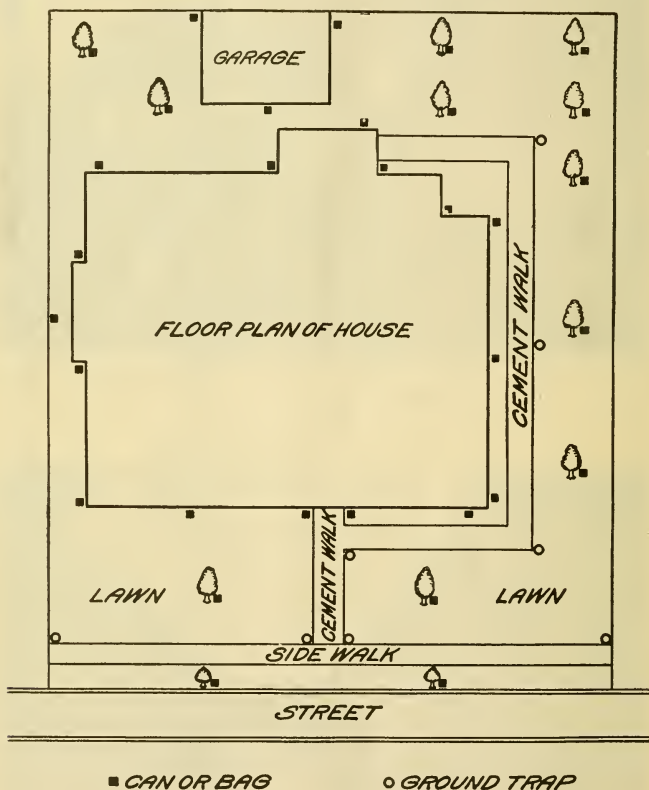


FIG. 20.—Diagram of residential property showing distribution of poisoned-sirup containers.

along sidewalks and about lawns where trails are located. A satisfactory distribution of containers on a 50 by 200 foot lot is shown in figure 20.

COMPREHENSIVE DEMONSTRATION OF CONTROL.

A campaign directed toward the control of the citrophilus mealy-bug was started at Upland in 1917, and it was soon discovered that the 600 infested acres were entirely overrun with the Argentine ant.

Therefore an effort to eliminate the ant was immediately started, and on August 28 ant poison prepared according to the original Barber formula was placed in paraffined paper bags on a 2-acre demonstration orchard, a bag to each tree. Within two weeks the effectiveness of the sirup was apparent, a reduction of fully 50 per cent being shown over the adjacent untreated trees. Within a month the ants were under control on most of the trees.

This very successful demonstration proved immediately convincing to orchardists in the neighborhood, and by the months of September and October the owners, representing 160 acres of infested orchards, had been induced to attempt ant control. During 1918 the territory covered was greatly extended and by the end of the year the treated territory had been brought up to 490 acres, or only 110 short of the entire mealybug-infested territory. These 110 acres were placed under control during the spring of 1919.

The methods which have been put into operation by the writers and are fully presented under demonstration orchard B were applied throughout the campaign. The original Barber poisoned sirup was used during 1917, but in 1918 the modified more dilute sirup was adopted and subsequently used exclusively. A very large amount of the poisoned sirup was prepared under the direction of the junior author or was supplied by qualified druggists. Spice tins were used very largely as containers.

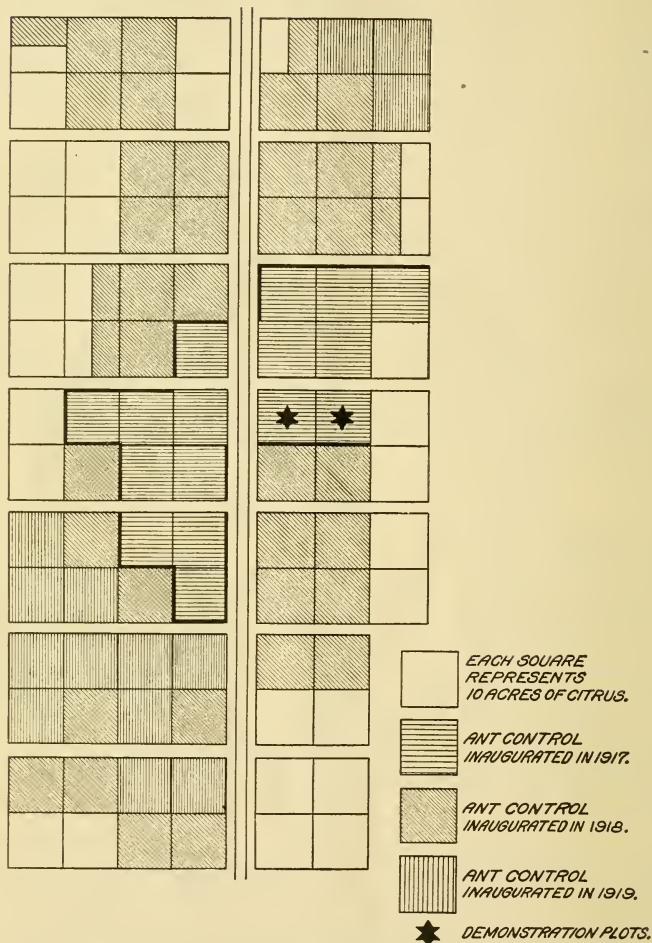
The results of these very extensive control operations were entirely satisfactory. Total eradication of ants over a large acreage was accomplished during 1918. In the spring of 1919 a careful inspection was made of all the acreage on which control had been attempted, the results of which are shown in figure 21. At that time the ants had been entirely eradicated over approximately 450 acres, including the territory over which control was started in 1917. The entire area was under control by the spring of 1920.

The cost of control for the whole district averaged between 4 and 5 cents per tree.

SUMMARY.

An investigation of methods for control and eradication of the Argentine ant was started in 1915 and continued until 1920. The methods used included banding of trunks to prevent the access of the ant, trap nesting, repellents, and the use of poisoned sirup.

Of the various substances tried in banding, a mixture composed of 1 part of sulphur and 6 parts of commercial sticky tree-banding material proved most satisfactory. The careful attention necessary to keep the bands in a freshened condition, their high cost, and the outstanding fact that the ants remained an everlasting menace, however, led to their discontinuance.



YEAR	1917	1918	1919	TOTAL
NEW AREA UNDER CONTROL	160	330	140	630
COMPLETE ANT ERADICATION		150	300	450
ENTIRE AREA UNDER CONTROL IN 1920.				

FIG. 21.—Diagram of the area under Argentine ant control at Upland, Calif., 1917-1919.

Trap nesting proved to be impractical under southern California conditions because of the light average rainfall and the excessive cost as compared with that of the use of a poisoned sirup.

Repellents, in the form of corrosive-sublimate bands and powders prepared from pyrethrum and sodium fluorid, were found to have a limited use about residences, apiaries, etc.

The most practical means of control was the complete eradication obtained by the use of an arsenical poisoned sirup. Numerous formulas were prepared and tried in large field experiments. Of these the original Barber formula proved effective, but was objectionable because of rapid crystallization. Various modified formulas were used and one finally adopted which contained all the ingredients of the Barber formula, somewhat reapportioned, and, in addition, the preservative benzoate of soda. The modified formula gives a much thinner sirup, one of greater stability, and also a considerably cheaper one. The arsenical poisoned sirups have been used in various parts of southern California on almost 3,000 acres of citrus with excellent results. Ants have been totally eradicated from many hundreds of acres with one or two applications. It is essential that the sirup be carefully and properly prepared.

Orchard control.—In orchard distribution approximately $1\frac{1}{2}$ ounces of sirup are placed in a 4-ounce spice tin with a few strands of excelsior, and such a tin is hung on the trunk or a main branch of each infested tree. Spring and autumn are the preferred periods for this work. Monthly inspection should be made and empty and removed containers refilled and replaced. The average cost per tree has been between 4 and 5 cents.

Control about residences.—This method has proved equally successful in eradicating the ants about residences. Much care should be given to bait each trail, at intervals of 10 to 15 feet, with either a spice tin or a ground trap.

The eradication of the Argentine ant has resulted in commercial control of mealybugs and the soft brown scale over a large area in the citrus districts of southern California.

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BULLETIN No. 966

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

August 25, 1921

THE EUROPEAN HORSE-RADISH WEBWORM.¹

By F. H. CHITTENDEN,

Entomologist in Charge, Truck-Crop Insect Investigations.

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INTRODUCTION.

Horse-radish grown in the northern United States and in Canada is subject to attack by a medium-sized caterpillar known both as the purple-backed webworm and the horse-radish webworm. Like so many of our insect pests, this species is of foreign origin and gained entrance into this country many years ago, but until recent years it has not been known to spread materially. While favoring horse-radish, it is also known to attack turnip and cabbage, and after feeding on the lower surface of the leaves sometimes webs them together near the ground. When abundant it attacks the stalks, even down to the roots.

Prior to the year 1919, when this webworm was first discovered in injurious numbers in Virginia near the District of Columbia, reports of injurious occurrences were nearly all confined to the maritime Provinces of Canada, although attack had been noted occasionally in Massachusetts, New York, New Jersey, and Wisconsin. The insect has been known to occur in the District of Columbia for several years, but heretofore it has been somewhat of a rarity.

This species makes the third specific enemy of horse-radish inhabiting North America, the other two being the introduced horse-radish flea-beetle (8)^{2, 3} and the native horse-radish webworm (9).⁴

¹ *Evergastis straminealis* Hübner; order Lepidoptera, family Pyralidae.

² *Phyllotreta armoraciae* Koch.

³ Numbers in parentheses (*italic*) refer to "Literature cited," page 10.

⁴ *Plutella armoracia* Busck.

Two other webworms affect horse-radish in the United States, both introduced from abroad, namely, the imported cabbage webworm (7)⁵ and the diamond-back moth (10).⁶

DESCRIPTION.

THE MOTH.

The moth of this species is rather bright ocher yellow and the forewings are traversed by two irregular lines dividing the wing into thirds of nearly equal width. Near the tip of the forewing is a conspicuous lighter spot and another larger rounded one near the middle of the anterior border. Directly outward from this latter there is an angular 8-shaped spot. The wing expanse is about 1 inch (25 mm.) and the length of the body a little less than half an inch (10 mm.). This moth resembles in general contour the related *E. rimosalis* Guen., but may be readily distinguished by the characters given and with the aid of the accompanying illustration (fig. 1). In some individuals the outer edge of the forewing is much darker than in others, darker even than in *E. rimosalis*.

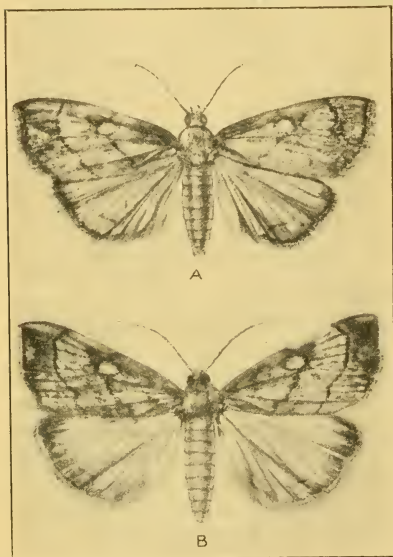


FIG. 1.—European horse-radish webworm (*Evergestis straminealis*): a, Moth, normal form; b, moth, dark form. Twice natural size.

The following more technical description is after Meyrick (5, p. 424):

Fore-wings pale ocherous-yellow, sprinkled with dark brown, veins posteriorly dark brown; lines dark fuscous, first angulated above middle, angularly indented above angle, second unevenly curved; an angularly 8-shaped discal spot, outlined with dark fuscous, touching angle of first line; a cloudy dark fuscous subterminal line, forming above middle a strong dark suffusion inclosing a pale terminal spot. Hindwings prismatic yellow-whitish; traces of a dark posterior line; termen narrowly dark fuscous.

⁵ *Hellula undalis* Fab.

⁶ *Plutella maculipennis* Curt.

THE EGG.

The eggs (fig. 2) are deposited in compact masses containing from half a dozen eggs to a score or more. Both the egg and the mass are difficult to describe, the individual egg being scarcely separate from the mass.

The individual egg is irregular oval, the mass being arranged more or less irregularly, as in the case of a honeycomb. The color is a little brighter green than the leaf on which it is deposited and each egg is surrounded by an irregular ring of yellow spots arranged in chains numbering about 12 to 18 to an egg. There is strong overlapping, so that an egg mass resembles, very imperfectly, a mass of fish scales. The surface is finely reticulate and divided into shining, minute, irregular areas much like the surface of leather. The diameter is about 0.8 mm.

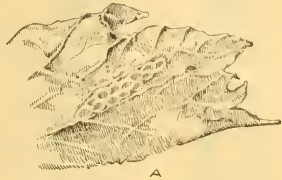


FIG. 2.—European horse-radish webworm: *a*, Egg mass *in situ* on leaf, three times natural size; *b*, section of surface of egg, highly magnified.

THE LARVA.

In the penultimate stage the larva (fig. 3) presents an appearance somewhat similar to the full-grown larva as regards the arrangement of the piliferous tubercles, but the form is more slender and the body tapers more at each end (the head being proportionately much smaller). The general color of the upper surface is purplish and has the peculiar appearance of being split through the middle, due to a wide pinkish longitudinal band separating the two parts between the rows of piliferous tubercles. The thoracic and anal plates are correspondingly smaller and faint yellowish brown.



FIG. 3.—European horse-radish webworm: Penultimate stage of larva. Much enlarged.

THE FULL-GROWN LARVA.

The full-grown larva (fig. 4) is elongate, cylindrical, about six times as long as wide, and tapers slightly toward each extremity, especially posteriorly. The general color is variable, generally either dull or shining dark slate gray above, sometimes faintly bluish. The lower surface is pale greenish yellow or yellowish, and the sides are marked with a narrow stigmatal line, orange about the spiracles and whitish or yellowish near the sutures. The head is shining jet black, faintly but distinctly separated, the delta-shaped middle portion longer than wide. The thoracic plate is piceous, the middle third or fourth paler, sometimes yellowish. The abdominal segments are without trace of transverse stripes; the piliferous tubercles are large and black; two pairs on the first two segments, the remainder arranged in groups of three, each side forming a triangle.

The anal plate is small, dull pale brownish. The sides have a row of substigmatal tubercles, one or two on each segment and another row midway between these and the legs; the legs are greenish or yellowish.

The length is 18 mm.; the width, 3 mm.

The larva has been described as purple, but the mature larva exhibits no evidence of this color in life. When preserved in alcohol there is a reddish and sometimes slightly purplish tinge.

The larva can be readily separated from that of *E. rimosalis* by the complete lack of transverse striation and by the black head.

When about to transform to pupa, the larva forms, usually at or near the surface of the ground, a substantial cocoon (fig. 5), which is evidently well coated on the exterior with a viscid substance to which particles of sand become at-

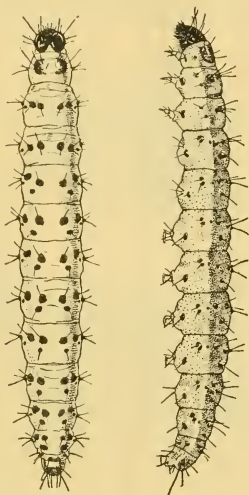


FIG. 4.—Full-grown larva of European horse-radish webworm: *a*, Dorsal view; *b*, lateral view. Four times natural size.

tached. These cocoons are large in comparison to the pupa and irregular short oval in shape.

THE PUPA.

The pupa (fig. 6) is of robust form with long wing cases

extending to the antepenultimate segment of the abdomen. It is widest below the middle across the wing cases and at its widest part is three-eighths as wide as long. The general color is brownish yellow, but the wing cases have a distinct greenish tinge. The eyes are large and black. The last abdominal segment is prolonged and unarmed.

The length is 8 mm.; the width, 3 mm.



FIG. 6.—European horse-radish webworm: Pupa. Six times natural size.

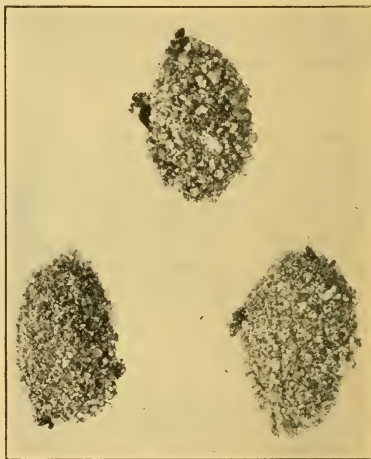


FIG. 5.—Cocoons of European horse-radish webworm. Much enlarged.

DISTRIBUTION.

Evergestis straminealis is native to the Old World, where it is found in Central Europe and in Great

Britain and Ireland. In Canada it has been reported from Cape Breton Island, Little Bras d'Or, Old Chelsea, Quebec, and Nova Scotia. In the United States it has been established for many years at Cambridge, Mass. Specimens are in the United States National Museum and it is noted as occurring in the following localities: Albany, Rochester, Kendall, N. Y.; Chester, N. J.; Cambridge and North Adams, Mass.; New Hampshire; northern Illinois; Madison, Wis.; Washington, D. C.; and Arlington, Va.

The known distribution is shown in the map (fig. 7).

NOTES OF OCCURRENCE AND HABITS.

The moth of this species was collected by the writer in September, 1898, at Washington, D. C., showing that it has evidently been established in this vicinity for several years, presumably feeding on horse-radish, though in small numbers, since it did not attract attention until 1919.

The records of the Bureau of Entomology show that the species was received July 27, 1903, from Dr. E. P. Felt, Albany, N. Y.

June 21, 1913, larvæ were observed attacking horse-radish at Chester, N. J., by H. O. Marsh. Larvæ under observation on June 30 burrowed into the soil and spun cocoons. The first of these transformed to pupa July 23, and the moth issued August 13, making the pupal period in this case 21 days.

June 14, 1914, specimens were received from Mr. Francis R. Foxcroft, with report that the larvæ were injuring turnip and radish at Cambridge, Mass., and that the leaves had been almost entirely devoured in that vicinity.

July 15, 1919, William H. White, Bureau of Entomology, observed larvæ on horse-radish at Arlington, Va., and later the writer observed this insect in the same locality.

Eggs which were deposited July 17, 1919, hatched July 24, and the larvæ from this lot, feeding on horse-radish leaves, began to transform to pupæ August 5. In this case the egg period was 7 days. The temperature was normal for the season, 64° to 91° F., and averaging 77° F.

By the third week of July, 1919, all moths from larvæ in confinement had issued from the cocoons; but another lot containing many



FIG. 7.—Distribution of European horse-radish webworm.

individuals living in a rearing cage in the open descended into the earth and when pupal cases, which were not far from the surface of the earth, were examined much later, it was found that the larvæ were unchanged and that no moths had issued.

During October it was observed that larvæ were again infesting the same horse-radish patch where first discovered at Arlington, Va., and by October 17 considerable injury had been done to the foliage, quite as much showing at this time as that done by the harlequin cabbage bug during the season. Where the leaves were dead and dry and were more or less loosely matted together, the larvæ were invariably found; indeed, they infested the entire patch from one end to the other. Larvæ were rapidly growing to maturity at this time, feeding sparingly and sluggishly during the cool weather which prevailed when under observation in the field. Characteristic injury to the lower leaves as inflicted in midseason is shown in figure 8.

Larvæ feed in colonies at first, but with the period of approaching maturity they are soon to be found singly and well scattered throughout the field. Some few are protected by white silken webs joining two leaves together or by drawing a single leaf somewhat lightly at the middle near the midrib. The great majority, however, are freely exposed, although sheltered from the sun by overhanging foliage. They feed for the most part near the midribs and near the middle of the plant, seldom near the outer ends, which as the season advances become for the most part dead and dry.

From the hatching of the larva until its maturity the life history of the species is well told by Buckler (4) as follows:

The newly-hatched larva is green, and rather transparent, with a flattened black shining head and dark brown neck-plate, and on the body can just be discerned most minute black dots and hairs; after eating out little pits and channels from the cuticle, causing transparent blotches on the leaf for about five or six days and acquiring more colour, it becomes of a very pale watery-green as it lays up to moult.

After the first moult it eats holes quite through the leaf, and its ravages are very perceptible; its head is black, the back dark green, the belly pale watery-green, the sides of the shining neck-plate dark brown, while the middle of the plate is of the same green colour as that of the back, the wart-like spots are of the ground colour but have dark brown centres bearing single hairs, and a pale ring is at the base of each spot.

Soon after the second moult it is very dark on the back with a deep and subdued blackish olive-green colour, while the belly has a much lighter tint of the same, these are separated by a spiracular stripe of bright yellow, the head, the side margins of the neck-plate, and the warty spots on the upper surface are shining black, on each side of the back are two very fine and much interrupted series of white linear dots, less broken on the second segment to the end of the fourth than on the others, the warty spots on the ventral surface are of the ground-colour, having dark olive-brown centres.

Directly after the third moult and for a day or so the ground-colour of the larva appears perfectly black, which enhances the brilliancy [brilliance] of the

broken white lines and the yellow spiracular stripes, but by degrees, after it settles down to feed again and grow, the black skin expands and the ground-colour of the back becomes more and more green until it is again of a blackish olivaceous-green, when the length ranges from 13 to 16 mm.



FIG. 8.—Horse-radish leaf skeletonized by the European horse-radish webworm.

It now consumes a great quantity of food and the plump skin begins to shine a little; at the end of about ten days it attains full-growth.

HISTORY IN NORTH AMERICA.

The species was described by Hübner from Europe in 1792 (1) and must have been introduced into this country, probably with its favorite food plant, at an early date, since it came under the observation of Harris in 1841 (3, p. 322). In Harris's notebooks appear the following memoranda:

Oct. 30 and Nov. 1, 1841. Found on leaves of horse-radish.

They eat large holes out of leaves, leaving finally only the veins untouched. They live beneath the leaves, stretched out by the sides of the midrib. They creep regularly, not haltingly, and move pretty fast. When alarmed or disturbed they curl quickly, and lose their hold, and fall to the ground. . . . Found the same on turnip leaves, Oct. 20, 1844. their ravages very considerable.

This account includes a description and a reproduction of a sketch of the larva, which are omitted here. Walker's description appeared in 1859 (2, p. 756) and was based on specimens from the United States and Nova Scotia.

An account of this insect by William Buckler (4) appeared in 1882. Not knowing the insect's food plants, but judging that it would live on Cruciferae, he placed the eggs on different plants. In confinement the larvæ fed freely on *Barbarea vulgaris*, *Sinapis arvensis*, and *Cardamine amara*. Larvæ molted three times, as follows: The first molt occurred August 8 to 10, the second August 17 and 18, and the third August 24 to 27. By September 29 all were full-fed and were inclosed in cocoons of earth. The moths began to issue June 20 of the following year, continuing emergence up to July 27. Buckler describes the egg, stating that it hatched in 8 days, the newly hatched larva, the different molts, and the cocoon.

Many years after Harris's first account, Dr. James Fletcher (6, p. 231) furnished the second account, and writes in 1904 that occasional reports had been received at different times for 10 years of attack on cabbage and turnip in the maritime Provinces of Canada. The caterpillars were described as congregating on the crowns of turnips and eating cabbages into the roots as well as consuming the leaves. Whole fields of cabbage and turnip were destroyed at Cape Breton Island. The larvæ were described as starting under the leaves just out of the ground and mining their way up to the head, tunneling it hollow. Injury was also reported to cabbage in 1903 at Old Chelsea, Quebec, Canada, and an original description of the larva was included.

In 1918 a popular account of this species was published by Messrs. Crosby and Leonard (11, p. 19-20).

FOOD PLANTS.

Harris recorded *Evergestis straminealis* on horse-radish and turnip, and Fletcher noted attack on these plants and on cabbage in Canada.

In Europe the species has been recorded as feeding in confinement on wild plants of the genera *Barbarea*, *Sinapis*, and *Cardamine*.

NATURAL ENEMIES.

This species is apparently unusually free from natural enemies, judging by the experience gained from two years' study in the vicinity of the District of Columbia. A single parasite, *Bracon montrealensis* Morrison (Clttn. No. 6076⁹¹), determined by A. B. Gahan, was reared from the larva of this species September 6, 1919, at Arlington, Va.

CONTROL.

It is evident, considering the fact that only one natural enemy of this species is known, that little can be expected from natural agencies of control. The arsenates of lead and lime and arsenite of zinc will all undoubtedly operate against the larva with equal value when applied for other cabbage worms. Underspraying is necessary, because of the habit of the larva of feeding mostly in concealment near the base of the plant. Hand-picking, if carefully carried out, is also of value when the species does not occur in too large numbers, as in the case of the infestation at Arlington, Va.

In the occurrence of this species on horse-radish, it is more difficult of control than on cabbage and other annuals. On such crops fall and spring plowing and frequent cultivation would undoubtedly be of great service in destroying the insect in its pupal cases, which are usually at or near the surface of the ground. Plowing could not be practiced in beds of horse-radish, and here many of the pests would survive the winter unless a spray were applied, which should be done in case of severe infestation.

SUMMARY.

Horse-radish, and less often turnip and cabbage grown in the northern States, are subject to attack by the European horse-radish webworm (*Evergestis straminealis* Hübner), a greenish caterpillar with reddish or purplish tints, measuring, when full-grown, about three-fourths of an inch in length.

It feeds on the lower surface of the leaves, which it frequently webs together near the ground, and also attacks the stalks.

This insect came originally from Europe, and has recently made its appearance on horse-radish in Virginia. It is known to occur from New England westward to Wisconsin.

It passes the winter as a larva in an earth-covered pupal case near the surface of the ground and the moths appear some time in May. In Virginia the eggs hatch in 7 or 8 days, and the larvæ begin by

feeding on the leaves, when abundant attack the stalks, and attain full growth in about 3 weeks. They then transform to pupæ, and about 3 weeks later produce another brood of moths, making an approximate life cycle of 7 or 8 weeks, depending on temperature. At least two generations a year are produced in Virginia.

This webworm may be controlled by arsenicals and by hand-picking on horse-radish and, more readily on other crops, by fall and spring plowing and frequent cultivation.

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BULLETIN No. 967

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

October 14, 1921

RESULTS OF WORK ON BLISTER BEETLES IN
KANSAS.

F. B. MILLIKEN, *Scientific Assistant, Truck-Crop Insect Investigations.*

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INTRODUCTION.

In the drier portions of western Kansas and adjoining States the insect fauna is particularly rich in blister beetles. Besides those of common occurrence elsewhere there are several species that are characteristic of the region. The native grasshoppers develop regularly in considerable numbers, thus insuring sustenance for some, at least, of the blister-beetle larvæ. The beetles feed on native legumes and other plants that root deeply and make some growth even when cultivated crops and shallow-rooted weeds die of drought.

The abundance of blister beetles in this region was noted by early entomologists, mostly systematists, who chanced through the western and southwestern United States; but it remained for Dr. C. V. Riley,

while entomologist of Missouri, to work out the first life histories of American species, and later as a member of the U. S. Entomological Commission to extend his researches in this line. Riley studied only species of general occurrence and only two of them to completion, yet he announced as his opinion that the life histories of other species would be found strictly parallel to these.

With the subsidence of outbreaks of the Rocky Mountain grasshopper (*Melanoplus spretus* Uhler), the Commission directed its attention to the more pressing problems of thickly settled portions of the country. The writer knows of no further study of the economic relations or biology of American species of this group.

The data on blister beetles that form the basis of this bulletin were collected, except as otherwise specified, since 1913. From March, 1913, to May, 1915, inclusive, the work was conducted at Garden City, Kans. From June, 1915, to June, 1917, inclusive, it was continued at Wichita, Kans. As the beetles do not occur there in sufficient numbers to supply the necessary material, work on control measures was dropped, and only such life-history work was conducted as was possible with material collected on infrequent trips at irregular intervals to western Kansas.

ECONOMIC IMPORTANCE.

There has been a tendency among entomologists to class the western species of blister beetles as beneficial. This arises from the fact that their larvæ feed on the eggs of grasshoppers, from the ravages of which the early agriculture of the plains region suffered immensely. However, the species of grasshopper responsible for a large share of the injury, and the one that stands to-day an insect bogey to those of limited entomological knowledge, has disappeared from the scenes of its former activity so completely that specimens of it are curiosities to the new generation of entomologists.

Only since the agricultural possibilities of the semiarid regions have been developed along diverse lines has it been possible to form a true estimate of the economic status of blister beetles. The presence of extensive acreages of sugar beet, alfalfa, beans, and peanuts has allowed them to exhibit to the full their propensity as crop destroyers. The cultivation of large areas and the close pasturage of a great deal more have also altered the flora and environment to such an extent that the former equilibrium of the insect fauna has been disturbed. Cultivation has insured a much more extensive food supply for grasshoppers, and they have become distributed accordingly; but much of this increase in the food of grasshoppers has not been accompanied by a corresponding increase in food suitable for the adult blister beetles. The latter have, therefore, been

unable to spread so widely. Pasturage or other disturbance incident to the agricultural use of the land has proved a greater detriment to the blister beetles than to the grasshoppers. Even in localities where blister beetles are most abundant repressive measures for grasshoppers have been found necessary. Also, where blister-beetle larvæ infest a large percentage of the grasshopper egg capsules, they must destroy many larvæ of the beefly *Anastoechus nitidulis* Fab., and of the hymenopterous egg parasite *Scelio monticola* Brues, neither of which is known to be injurious in any stage. The larvæ of the beefly destroy a great many more grasshopper eggs than the larvæ of the blister beetles, but are helpless against the latter when they enter the same egg capsules.

It is questionable whether blister-beetle larvæ have ever been sufficiently beneficial to offset the damage done by the adults. Certainly they are now relatively of much less value than formerly. The group, therefore, must be considered injurious and will become more so with continued agricultural development of the semi-arid sections.

INJURY TO CROPS.

Blister beetles may devour only the petals and pollen of the flowers. They usually do this on beans, peanuts, and locust trees, and largely on alfalfa. On Irish potatoes, sugar beets, and to a lesser extent on the Russian olive, however, they commonly defoliate the plant. In either case the actual injury to the crop depends on the stage of growth which the plants have reached. When they are near maturity the yield is lessened, but the crop is not a total loss. Unless drought prevails at the time of defoliation, sugar beets usually put forth new leaves and continue their growth, but the effect of defoliation is recorded in decreased tonnage or sugar content, or both. A defoliation of Irish potato is usually disastrous, as is also the destruction of the blossoms of beans and of peanuts.

FOOD PLANTS.

Leaf-feeding insects, like the blister beetles, could not become as numerous in the semiarid regions as they do without the presence of some hardy native plant upon which they can feed during drought. At Garden City, Kans., the beetles feed upon the blossoms of the sunflower (*Helianthus* spp.), the goldenrod (*Solidago* spp.), the leaves and flowers of the few-flowered psoralea or scurvy pea (*Psoralea tenuiflora*), and on other prairie legumes. They also feed extensively on an introduced weed, the ground burnut (*Tribulus terrestris*).

The cultivated plants which they attack most extensively are the Irish potato (*Solanum tuberosum*), the sugar and garden beets (*Beta*

vulgaris), alfalfa (*Medicago sativa*), the garden bean (*Phaseolus* spp.), the peanut (*Arachis hypogaea*), and sweet clover (*Melilotus alba*). The writer has not noticed them feeding much on other plants, but references to literature show that they attack a great variety of vegetation.

As the beetles emerge they begin feeding on such plants as they find near by. Later they are driven to cultivated plants, because drought has killed the weeds or because they need a more abundant and continuous food supply to support them in their gregarious habits.

CLASSIFICATION OF SPECIES STUDIED.

The blister beetles belong to the coleopterous family Meloidae, the members of which contain in their bodies a substance that blisters when extracted and applied to the skin. Both subfamilies, Meloinae and Cantharinae, are represented in these studies, though only one genus of Meloinae was identified. This was *Meloe*, about 30 specimens of an undetermined species of which were collected (Chttn. No. 2507). All of these were found along a short piece of roadway which was flanked on one side by a field of wheat and on the other by a weedy prairie pasture. The species may have been only recently introduced in this locality, as it was but a few rods from the bank of a main irrigation ditch which comes directly from the Arkansas River. It was not to be found elsewhere at Garden City. Specimens were secured April 24, May 7, and May 19, 1914. On May 7 one

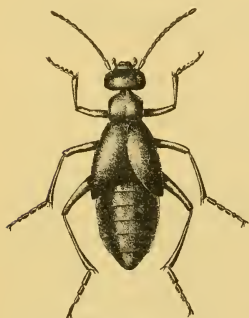


FIG. 1.—*Meloe afer*: Adult.
Enlarged.

pair was taken in copula, but no eggs were secured. The immature stages were not observed, nor were the beetles seen feeding except on the young Russian thistle.

DESCRIPTION OF MELOE SP.

ADULT.

Near *afer* Bland. or *barbarus* Lec. (Chttn. No. 2507) : Length, 8 to 12.5 mm.; width, 3 to 4 mm.; elytra diverging, truncated, the body being widest across the abdomen near their tips; color black; rough and feebly shining. (Fig. 1.)

Of the subfamily Cantharinae, two tribes, Nemognathini and Cantharini, were represented.

The specimens of Nemognathini were identified as belonging to one genus and three species, *Nemognatha lurida* Lec., *N. bicolor* Lec., and *N. piezata* Fab. They were intermingling freely on blossoms of

the bull-thistle (*Cirsium lanceolatum*) and on account of their intergrading color patterns could easily have been referred to a single species. They were not observed in any injurious connection, and their immature stages were not found.

The tribe Cantharini was represented by three genera—*Macrobasis*, *Epicauta*, and *Cantharis*. To *Macrobasis* and *Epicauta* belong the injurious species occurring at Garden City, Kans., and they are treated at length in this paper. Of the genus *Cantharis* only one species was identified, *Cantharis reticulata* Say, of which a very few specimens were collected. They are sufficient for only a brief description.

DESCRIPTION OF *CANTHARIS RETICULATA* SAY.

ADULT.

Length, about 15 to 25 mm.; width, about 4.5 to 7 mm.; color black, except antennæ and legs, which are dark brown. Elytra irregularly ridged, hence the name; head, thorax, and abdomen pitted and sparsely haired; legs thickly haired. (Fig. 2.)

The adults were taken on the bush morning-glory (*Ipomoea leptophylla*), excepting one which was found on alfalfa.

Besides *Cantharis reticulata*, the tribe Cantharini is represented at Garden City by at least 15 species, of which four belong to the genus *Macrobasis* and 11 to *Epicauta*. For the purposes of this paper the generic and specific distinctions are sufficiently set forth by the key, which has been adapted from Horn with the assistance of H. S. Barber, of the United States National Museum.

KEY TO SPECIES OF *EPICAUTA* AND *MACROBASIS* COLLECTED AT GARDEN CITY, KANS.

- A. Second joint of antennæ at least half as long as third.....*Macrobasis*.
 - a. Black with posterior margins of abdominal segments gray.
 - M. segmentata* Say.
 - aa. Gray, yellowish, or brownish, unicolorous or with markings.
 - b. Prothorax usually with two longitudinal black stripes; elytra usually concolorous, sometimes with submarginal black stripes; basal joints of antennæ brown (fig. 3).....*M. albida* Say.
 - bb. Unicolorous.
 - c. First joint of antennæ as long as or longer than the second and third together. In the male it reaches to the occiput, and the second is at least twice as long and twice as thick as the third.....*M. unicolor* Kirby.
 - cc. First joint of antennæ similar in sexes, second joint shorter than third.....*M. immaculata* Say.

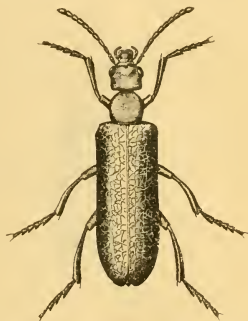


FIG. 2.—*Cantharis reticulata*: Adult. Enlarged.

AA. Second joint of antennæ less than half as long as third-----*Epicauta*.

a. Antennal joints elongate, loosely united.

b. Unicolorous.

c. Gray or yellowish-----*E. cinerea* Forst.

cc. Black.

d. Large, 25 to 30 mm. long-----*E. corrina* Lec.

dd. Less than 20 mm. long.

e. Spurs of hind tibia stout, cylindrical; length 12 to 20 mm. (fig. 4)--*E. funebris* Horn.

ee. Spurs of hind tibia slender, acute at tip and unlike, the outer spur being broader; length 8.5 to 14 mm--*E. pennsylvanica* DeG.

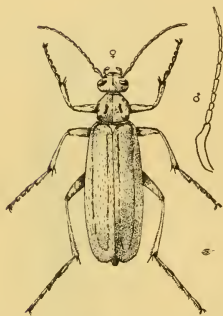


FIG. 3.—The two-spotted blister beetle (*Macrobasis albida*): Adult, striped variation. Enlarged.



FIG. 4.—*Epicauta funebris*: Adult. Enlarged.

bb. Variegated.

c. Gray or yellowish with black markings.

d. With three longitudinal black stripes on each elytron-----*E. icmnicata* Fab.

dd. Spotted with black.

e. Spots minute, scattering----*E. maculata* Say.

ee. Spots larger, crowded, sometimes coalescent.

E. pardalis Lec.

cc. Black, elytra and prothorax margined with gray, and median line of prothorax gray-----*E. marginata* Fab.

aa. Antennal joints short, closely united.

b. Pronotum with pair of bare, smooth, black areas; color reddish or grayish brown-----*E. callosa* Lec.

bb. Pronotum unmarked.

c. Surface of pronotum moderately shining under vestiture-----*E. ferruginea* Say.

cc. Surface of pronotum opaque-----*E. scricans* Lec.

The only distinction between *Macrobasis* and *Epicauta* is in the relative length of the second segment of the antennæ (figs. 5, 6). In

Macrobasis it is at least half as long as the third and usually more. In *Epicauta* it is less than half as long as the third.

The four species of *Macrobasis* are easily distinguished, and no well-marked varieties in a species were observed. But there is great variation in the shade of color, especially in *M. immaculata*, and in the extent of the black submarginal stripes on the elytra in *M. albida*.

These stripes next the outer and the inner margin of each elytron, if present, may extend so far as to unite at the distal end, forming a U that opens anteriorly. The black stripes on the prothorax may sometimes be lacking, but so rarely that it was not noted in the key.



FIG. 6.—*Epicauta corvina*;
Antenna. Much enlarged.

As might be expected, since *Epicauta* is so much more richly represented than *Macrobasis*, it has greater variation within its species; also the separation of the species is much more difficult.



FIG. 5.—The spotless blister beetle (*Macrobasis immaculata*); Antenna of male. Much enlarged.

CHARACTER OF ADDITIONAL DATA ON MACROBASIS AND EPICAUTA.

In the rearing work eggs of several species were secured in confinement and hatched, giving authentic eggs and triungulins. No larvæ have been carried through the growing stages. Attempts to do so were thwarted by the high percentage of parasitism which existed among grasshopper egg-capsules that were collected for the purpose, and the writer was unable to secure eggs of grasshoppers by confining them. Coarctate larvæ were collected and kept under observation during the succeeding transformations. These yielded authentic material for the identification and description of the later stages.

In presenting the data relating to each genus the species on which they are most nearly complete will be considered first.

RESULTS OF WORK ON MACROBASIS.

DESCRIPTIVE.

MACROBASIS IMMACULATA SAY.

ADULT.

Macrobasis immaculata is among the largest blister beetles found in Kansas. A number taken at Garden City averaged 17.5 mm. long by 4.5 mm. wide. Blatchley gives the limits of its variation in length as 13 to 23 mm. Color gray to light reddish brown. According to Blatchley, the sexes are distinguished by the third antennal joint in the male being longer than the second, but in the female of only equal length or shorter.

EGG.

Length, 1.5 mm.; width, 0.5 mm.; shape almost cylindrical, but tapering slightly toward the posterior end; color translucent yellowish white.

LARVA.

Triungulin (fig. 7).—Length, 2.7 mm.; width, 0.5 mm. through the head; shape elongate triangular, tapering gradually to the posterior end, which is bluntly rounded; color yellow or light brown, with lighter bands on the parts

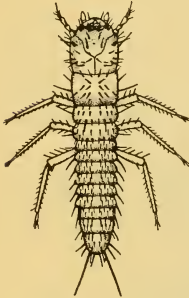


FIG. 7.—*Macrobasis immaculata*: Triungulin.

of segments that fold against one another when the body contracts in length; legs 3-jointed, strong; claws three in number (hence the name triungulin), slender, the two outer ones spinelike; eyes apparently only pigmented spots behind the antennae on the anterior part of and near the outer margins of the head; mandibles flat, sickle-shaped, strong, with notched inner margins; antennae apparently 3-jointed, the third joint divided with the dorsal portion the larger and bearing several spinose hairs; spiracles 9 in number and located above the lateral margins; armature of abdomen consisting of spinose hairs, about 10 in a transverse row near the posterior margin of each segment, and about 6 in a row nearer the anterior margin, those in each row so placed as to be in rows with corresponding hairs on the other abdominal segments; anal segment with two diverging hairs one-fourth to one-third length of body, projecting posteriorly from above its tip; hairs also regularly placed on thorax, head, and upper and outer surfaces of mandibles; legs with stiff hairs projecting perpendicularly on the femur but appressed on the tibia.

Carabidoid and scarabaeidoid larvæ.—Descriptions of these stages could not be secured from authentic specimens, as they were not reared. Collected larvæ that were thought to be in these stages were similar to those figured by Riley¹ for *Epicauta vittata*.

Coarctate larva (fig. 8).—Length, 11.5 to 13.5 mm.; width, 4.5 to 6.5 mm.; shape elongate hemispherical, resembling the half of a peanut kernel if the ends of the latter were bent toward its flat side and its edges thickened; color reddish brown; entirely inactive, the skin rigid; location of appendages shown by tubercular projections; limits of head shown by a constriction near the anterior end; segmentation of body plainly shown dorsally but less distinct ventrally; spiracles in shallow depressed line above the thickened edges.

Third larva.—Measurements difficult to make, though greater than for the coarctate larva; color white; shape robust, fleshy, and much wrinkled. larva

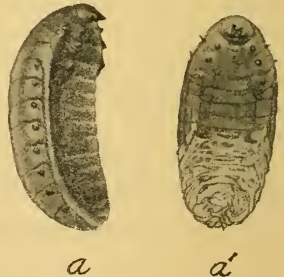


FIG. 8.—*Macrobasis immaculata*, coarctate larva: a, Lateral view; a', ventral view. Enlarged.

¹ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS. FIRST ANNUAL REPORT, U. S. Ent. Comm., Dept. Interior, U. S. Geol. Survey, 1877, pl. IV, figs. 4-7. 1878.

assuming a horseshoe shape when at rest; head horny, yellowish, with front almost vertical; mandibles brown, curved; antennæ situated above the outer edges of the bases of the mandibles, apparently three-jointed, with two fleshy projections on the distal end of the third segment; first and second antennal segments with basal rings of brown and third segment brown for almost its entire length; eyes minute black spots above the bases of the antennæ; sutures extending diagonally backward from the bases of the antennæ, meeting at the median line above the middle of the front; labrum separated from the front by a brown suture; legs fleshy, jointed, the distal ends thickly studded with stiff brown spines; spiracles on second body segment and on fourth to eleventh, inclusive.

PUPA.

Length, about 17 mm.; width, about 7 mm. (measured from tip to tip transversely extended femora); color yellowish white with translucent appendages; head appressed on prothorax until front is almost parallel with body; femur and tibia of each leg folded together and extending forward, upward, and outward; tarsi extending posteriorly on the venter; antennæ extending posteriorly dorsal to the anterior and middle legs; posterior margins of prothorax and abdominal segments bearing stiff, curved spines.

MACROBASIS UNICOLOR KIRBY.

ADULT.

Specimens of *Macrobasis unicolor* collected at Garden City, Kans., averaged about 13.6 mm. long and 3.4 mm. wide. Blatchley gives the limits of their variation in length as 8 to 15 mm. It is the slenderest of our species (fig. 9) and the sides are almost parallel; color ashy gray, sometimes with a yellowish cast, but more uniform than in any other species collected at Garden City, except the black ones.

EGG.

The eggs were not secured nor were the growing stages of the larvæ identified.

COARCTATE LARVA.

Five specimens vary in length from 10 to 12 mm., and in width from 4.5 to 5.5 mm. They are rather slender and of a yellowish brown color. In other ways they agree with the coarctate larvæ of *Macrobasis immaculata*.

THIRD LARVA.

Smaller and more slender than the corresponding stage in *M. immaculata*, but otherwise similar thereto.

PUPA.

The only specimen measured was 10 mm. long by 3 mm. wide. Though smaller and more slender it was otherwise similar to the pupa of *M. immaculata*.

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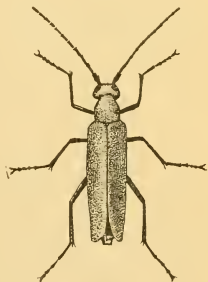


FIG. 9.—The ash-gray blister beetle (*Macrobasis unicolor*): Female beetle. Enlarged. (Chittenden.)

LIFE HISTORY AND HABITS.

MACROBASIS IMMACULATA SAY.

OVIPOSITION.

The female of *Macrobasis immaculata* deposits her eggs in small cavities (fig. 10) prepared in the soil wherever she may be feeding. In confinement no special preparation or arrangement could be observed. While on the staff of the Kansas Experiment Station the writer once observed oviposition in the field. The ovipositing female first came under observation about 3.30 p. m. She was busily engaged in excavating and continued thus as long as watched. The place was marked, and the writer returned at 6 o'clock to find her still at work. The next forenoon the spot where the beetle had worked had been

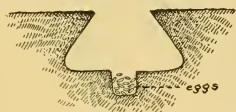


FIG. 10.—Cavity prepared for eggs by female of *Macrobasis immaculata*.

smoothed over, nothing remaining to indicate the location of the eggs except the identifying marks. Careful excavation revealed the outlines of a bell-shaped cavity in which the dirt had been replaced and loosely packed. In the center of the floor was a smaller cavity that contained a mass of several hundred eggs. The eggs were about $1\frac{1}{2}$ inches below the surface, and without definite arrangement or protective covering.

The earliest date at which eggs were secured in confinement was July 22 and the latest September 9.

INCUBATION.

As incubation proceeds the young larva soon becomes visible through the transparent shell. The body is translucent, distinctly segmented, and the head is closely appressed on the venter. The mouth parts extend backward below. The eyes are black, the tips of appendages brown, and the spiracles are ringed with brown. The hairs are closely pressed to the body, the two long ones on the anal segment being bent around so as to extend forward at the sides.

Eggs deposited July 22 hatched August 3, and some deposited July 24 hatched on August 5 and 6. The incubation period is thus from 12 to 14 days in length, but this becomes increased during cooler weather.

HABITS AND GROWTH OF LARVA.

The newly hatched larva soon becomes active. Where the beetles are numerous during the summer the little triungulins soon abound, and close observation will discover them hurrying about over the ground. They go into every crevice and under every clod and piece

of vegetable matter. Their mode of locating and entering grasshopper egg capsules has never been observed by the writer; but a few weeks later the large, plump, white scarabaeidoid larvæ and the reddish-brown coarctate larvæ have been found in capsules of grasshopper eggs. Probably a large percentage of the triungulins fail to find grasshopper eggs and perish from starvation. The fact that not more than one larva is ever found in a capsule indicates a further mortality through struggles between rival claimants for egg masses, since where the triungulins are so numerous it seems certain that more than one would enter each capsule of eggs.

All evidence that has been secured as to the rate of growth and the character of the accompanying transformations indicates that they are similar to and probably parallel with those described by Riley,² in the case of *Epicauta vittata*.

On becoming full grown the larvæ burrow away from the egg-capsules they have emptied, usually going much deeper, then turning toward the surface. There each larva forms an elliptical chamber at a slight angle with the perpendicular, stiffens out with the head uppermost, and sheds the old larval skin, which remains around the posterior portion of the abdomen. This leaves the elongate hemispherical coarctate larva standing almost vertically on end in the old exuvium and supported near the anterior end by the dorsal portion resting against the wall of the cell. The depth at which coarctate larvæ are found varies, being from 3 to 6 inches below the surface.

The coarctate larvæ have been found from late in summer until late the next spring. No scarabaeidoid larvæ large enough to belong to this species have been found during the winter or spring. This indicates that the species hibernates only in the coarctate larval stage.

After the spring's warmth penetrates to the coarctate larva the rigid skin splits along the anterior portion of the dorsal line. The third larva wriggles out and burrows toward the surface. The writer's earliest record of this transformation is dated May 28, but another record gives pupation on May 27, so it is safe to say that the third larvæ begin to appear in Kansas about May 20.

PUPATION.

After a few days' activity the third larva has approached to within 1 or 2 inches of the surface. Here it constructs an elongate cell at an angle with the horizontal of from 30° to 60°. It turns on its back therein (fig. 11) and begins transformation to the true pupa. The process requires several days, the exact time depend-

² RILEY, C. V., PACKARD A. S., and THOMAS, CYRUS. OP CIT., p. 299.

ing on the prevailing temperature. Pupæ have been secured beginning May 27 and continuing until August. Five that were handled in confinement between May 27 and July 24 had an average pupal period of 18 days.



FIG. 11.—Pupa of blister beetle *in situ* in cell.

the pupal period, finally involving the legs and oral appendages. During its struggles the beetle rights itself and explores the narrow confines of its chamber. A thin, transparent, parchment-like membrane loosens on the surface of its body and is torn beyond recognition by the sharp tarsal claws. Adults from pupæ that have formed against the walls of glass containers have remained in the cells for several days after transformation before digging to the surface. Whether or not such is the case when light is excluded was not determined.

MACROBASIS UNICOLOR KIRBY.

The data secured on *Macrobasis unicolor* add nothing to the general account given for *Macrobasis immaculata*. The third larvæ have been collected by April 15, and eight specimens secured by that time had yielded the adults by May 30. The data on *M. unicolor* indicate that it, also, hibernates as coarctate larva.

RESULTS OF WORK ON EPICAUTA.

DESCRIPTIVE.

EPICAUTA MACULATA SAY.

ADULT.

Adult specimens of *Epicauta maculata* (fig. 12) varied from 10 mm. long by 2.25 mm. wide to 13 mm. long by 3.5 mm. wide, which makes it one of the

EMERGENCE OF ADULT.

As the time for emergence approaches, the tips of the appendages begin to darken. The coloration spreads gradually throughout the appendages and into the body. Several days before the emergence of the adults twitching movements begin in the tarsi. These become more vigorous toward the end of

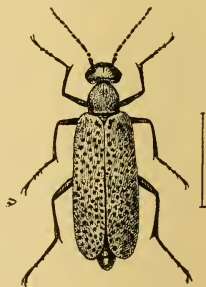


FIG. 12.—The spotted blister beetle (*Epicauta maculata*). Enlarged. (Chittenden.)

smallest of our common blister beetles. The color may be either light gray or yellowish, with scattered naked spots of the black background. The black spots vary both in size and location, being barely discernible on some beetles and at least 0.3 mm. in diameter on others.

EGG.

The egg of this species resembles that of *Macrobasis immaculata*, but is smaller.

LARVA.

Triungulin (fig. 13).—Length, about 1.25 mm.; width, about 0.4 mm.; widest in front of middle of head just behind eyes, from which point the head tapers posteriorly for the last half or more of its length. In this respect it agrees with triungulins of *Epicauta pennsylvanica* and *E. lemaiscota*,³ but differs from Riley's figure of *E. vittata*.⁴ The head of the latter is parallel-sided, resembling *Macrobasis immaculata*, but differing in having a very short posterior portion or neck and in having the eyes located about the middle of the length of the head. In all triungulins examined by the writer the eyes are located much nearer the anterior portion of the head.

In other respects the triungulin of this species resembles that of *Macrobasis immaculata* (p. 8).

Active larva.—Neither the growing stages nor the third larva were recognized so they could be described.

Coarctate larva.—The writer's records show one coarctate larva that measured 9 mm. long by 4 mm. wide which yielded an adult of this species.

PUPA.

The pupa of this species was not described for lack of authentic material. It is similar in color and appearance to that of *Macrobasis immaculata*, but much smaller.

EPICAUTA CINEREA FORST.

ADULT.

Length of adult *Epicauta cinerea* (fig. 14), from 8 to 17 mm.; width, 1.75 to 4 mm.; shape slender, with sides of elytra almost parallel; color, bluish to light or yellowish gray.

EGG AND ACTIVE LARVA.

Neither the egg nor any of the active larval stages of this species were secured for descriptive purposes.



FIG. 13.—*Epicauta maculata*; Triungulin. Enlarged.

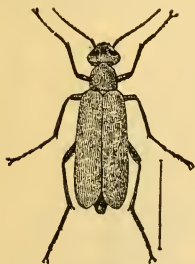


FIG. 14.—*Epicauta cinerea*: Adult. (Chittenden.)

³ Triungulins of this species were kindly furnished by Mr. Thos. H. Jones of the Bureau of Entomology.

⁴ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS, op. cit., Pl. IV, fig. 2.

COARCTATE LARVA.

Length of coarctate larva (fig. 15), 7.45 mm.; width, 4.08 mm.; 28 specimens varied in length from 6.25 to 9 mm. and in width from 3.25 to 5 mm. Shape much more robust than that of the coarctate larva of any other species thus far

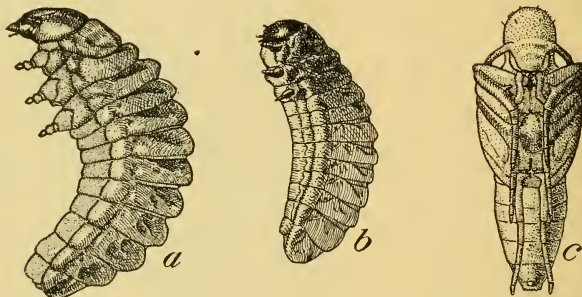


FIG. 15.—The gray blister beetle (*Epicauta cinerica*): a, Scarabaeidoid larva; b, third larva; c, pupa.

secured, being almost straight longitudinally on the venter and without the angular lateral ridges, thus leaving them almost circular in abdominal cross section; color a rich reddish brown, darker than any other species with which the writer has worked.

PUPA.

The single pupa (fig. 16, c) of this species which was measured had a length of 12 mm.

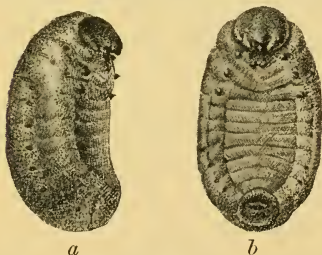


FIG. 16.—*Epicauta cinerica*: a, Coarctate larva, lateral view; b, coarctate larva, ventral view.

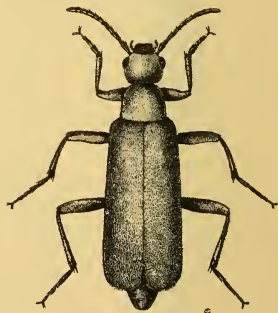


FIG. 17.—*Epicauta sericans*: Adult. Enlarged.

and a width of 4 mm. In shape, color, and general appearance it resembles the pupa of *Macrobasis immaculata*, but is not so large.

EPICAUTA SERICANS LEC.

ADULT.

Of 29 adult specimens of *Epicauta sericans* (fig. 17) the variation in length was from 9.5 to 13 mm., with an average of 10.8 mm.; color, light reddish brown through yellow and gray to almost silvery; antennae reaching to the elytra, the segments except the second being nearly as broad as long. The second segment is nearly twice as long as thick; sides of elytra nearly parallel.

EGG AND YOUNG LARVA.

The egg has not been secured or the growing stages of the larva recognized.

COARCTATE LARVA.

The average of 10 coarctate larvæ was 6.875 mm. in length by 3.8 mm. in width. They are reddish brown, but not so dark as those of *E. cinerea*, and the lateral ridges are present and distinctly angular.

THIRD LARVA.

The third larvæ are 7 to 8 mm. long by 2.5 to 3.5 mm. wide. In shape, color, and general appearance they resemble those of *Macrobasis immaculata*.

PUPA.

A description of the pupa has never been secured.

EPICAUTA PENNSYLVANICA DE G.

ADULT.

Epicauta pennsylvanica (fig. 18) is the smallest of the black blister beetles that occur in Kansas. Of 18 specimens, the length varied from 8.5 to 14 mm., averaging 10.3 mm., and the width from 2 to 4 mm., averaging 2.88 mm.; shape rather slender; color dull black.

Egg.

The egg resembles that of *Macrobasis immaculata*, but is much smaller.

TRIUNGULIN LARVA.

Length of triungulin larva (fig. 19) about 1.3 mm.; width about 0.3 mm., widest through the head about midway of its length, which is just behind the eyes, and tapering to the prothorax, into which it telescopes slightly; color, brownish yellow, translucent. In shape and general appearance it resembles the triungulin of *Macrobasis immaculata*.

None of the other larval stages have been secured, even the coarctate larva of this species having escaped recognition.

LIFE HISTORY AND HABITS.

EPICAUTA MACULATA SAY.

OVIPOSITION.

While on the staff of the Kansas Experiment Station the writer observed oviposition by a female of *Epicauta maculata*, as well as by a female of *Macrobasis immaculata*. Both were working at the same time, being discovered only a few yards apart in the edge of a field. The process was identical with both females, lasting from before 3.30 p. m. until after 6 p. m., as described under *M. immaculata*. The cavities to receive the eggs were made exactly alike—bell-shaped, with the flaring end down and the eggs reposing in a further depression at the center of the bottom of the bell; but the cavity made by *E. maculata* was only about 1 inch

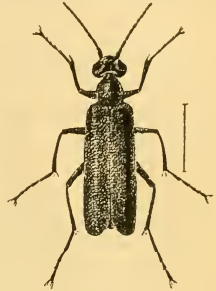


FIG. 18.—The black blister beetle (*Epicauta pennsylvanica*): Adult. Enlarged. (Chittenden.)



FIG. 19.—*Epicauta pennsylvanica*: Triungulin. Enlarged.

deep, as compared with $1\frac{1}{2}$ inches for the other. Several hundred eggs were in each nest.

In confinement eggs have been secured from July 27 to September 22. Confined females lose their instinct for careful oviposition, placing their eggs under a clod or leaf, or scattering them about on the surface without covering.

INCUBATION.

Incubation proceeds as described for *Macrobasis immaculata*. Eggs secured July 31 hatched August 18, and others deposited August 1 hatched August 22, giving an incubation period of from 18 to 21 days.

HABITS AND GROWTH OF LARVA.

The newly hatched larvæ soon become active. Their activities parallel those described for the triungulin of *Macrobasis immaculata*.

The coarctate larvæ are found near the surface, being but little deeper than the lower ends of the grasshopper egg capsules. Many are taken directly from the capsules. In confinement one third-stage larva appeared on May 6, the pupa was fully formed on May 12, and the adult came forth on May 25. The adults appear in numbers earlier than those of any other species of Cantharini taken in this region, this fact being corroborated by field observations. Since eggs were secured on September 27 it is evident that the adults occur throughout the summer.

EPICAUTA CINEREA FORST.

Oviposition by *Epicauta cinerea* has never been observed, nor have the habits of the larvæ preceding the coarctate been studied.

The coarctate larvæ have been collected at all seasons of the year and wherever grasshopper eggs are to be found. They occur from 2 to 5 inches below the surface in nearly upright cells, in which the larvæ are disposed as described for *Macrobasis immaculata*. The earliest date at which third larvæ have been collected was between April 12 and April 16. They are frequently found during the last week in May.

According to the writer's records the earliest pupation in confinement occurred May 8; but an adult for which the pupation was not recorded emerged on the same date, thus indicating pupation at least 10 days earlier. Other transformations follow rapidly and continue through the summer. From the dates recorded for the transformation of this species it would seem that its appearance in the field should precede that of *Epicauta maculata*, which, as stated above, is the earliest to appear of the Cantharini of this region. The apparent contradiction is reconciled by the occurrence of most of the coarctate larvæ at greater depths than those of *E. maculata*,

which prevents the reception of sufficient heat to start activity early in the season. Only those individuals of *E. cinerea* that are near the surface appear with the main brood of *E. maculata*.

EPICAUTA SERICANS LEC.

Adults of *Epicauta sericans* have been collected from June 6 to September 11. They are commonly found feeding in flowers on many kinds of plants, often being taken on sunflower (*Helianthus* spp.), other Compositæ, the scurvy pea (*Psoralea tenuiflora*), alfalfa, peanuts, and other cultivated legumes.

The eggs have not been secured or the growing stages recognized. The coarctate larvæ have been collected during the fall, winter, and spring, and emergence begins early in June. For these reasons this species is believed to develop normally one generation annually, hibernating as coarctate larva; but instances of retarded development have occurred, and these are considered under the proper heading.

EPICAUTA PENNSYLVANICA DE G.

The adults of the small black blister beetle have been collected at Garden City, Kans., from August 17 to November 11. At the latter date about half the adults had died, and the remainder were so stiff from cold that they could not cling to vegetation. They were first found on blossoms of the goldenrod (*Solidago* spp.), but later fed on the blossoms of the many-flowered aster (*Aster multiflora*), alfalfa, and a few other plants. Eggs were not found in the field, but were secured from adults confined on earth in a battery jar. On October 20 a cluster of 363 was deposited about half an inch below the surface. The eggs hatched on November 15, which was too late for development to proceed. This agrees with Riley's statement⁵ that the species evidently hibernates as the triungulin.

IRREGULAR DEVELOPMENT.

During the progress of these investigations some marked variations were observed in the time required for development. Of active, grown larvæ collected at Garden City, Kans., during the period from April 12 to 16, 1916, three transformed to coarctate larvæ of *Epicauta cinerea* by May 7. When examined again on May 29 they were found dead as third larvæ, having perished from lack of moisture. Under the circumstances it is impossible to say whether these specimens were mature scarabaeidoid or the third larvæ when collected. Most specimens of *Epicauta cinerea* that have

⁵ RILEY, C. V., PACKARD A. S., and THOMAS, CYRUS. Op cit., p. 301.

been reared came from coarctate larvæ that were collected during the fall and winter.

Seven mature coarctate larvæ of one type, collected during the winter of 1913-14 were placed on soil in a perforated tin box. During the summer the box was buried in the insectary at a depth of about 2 inches and forgotten. The writer chanced upon it again November 25, 1914, finding in it six coarctate larvæ, one dead third larva, and seven cast coarctate skins. Only one explanation is possible. The coarctate larvæ all transformed to the third larvæ, and six of them reverted to the coarctate condition again. The seventh perished. On May 30, 1915, the six coarctate larvæ were separated into two lots of three each. One lot was placed in dry earth, the other in damp earth. The former showed no signs of activity. Of those in moist earth, one had decayed by July 2, another had transformed to third larva, and the third specimen remained unchanged and apparently healthy. The third larva continued its transformations, and on July 24 yielded an adult of *Epicauta sericans*. The four unchanged coarctate larvæ were stored in dry soil until the spring of 1916. Upon being moistened they decayed at once.

A coarctate larva obtained during the winter of 1913-14 did not yield the adult until July 7, 1915. This proved to be *Macrobasis immaculata*.

Riley⁶ reports cases of retarded development in *Epicauta vittata* (figs. 20, 21). From the same batch of eggs he had beetles mature in one, two, and three years. Regarding one which required three years he wrote as follows:

In this case the individual, though submitted to exactly the same conditions as the other specimens, which had simultaneously hatched with it—but which went through all their transformations within either one or two years—remained dormant for nearly three years, with their repeated changes of season and temperature. With the exception of the first winter, when it was kept indoors without freezing and when development should have been presumably hastened, the specimen was kept in a tin box buried the proper distance beneath the ground out of doors, so as to be as nearly as possible under natural conditions.

Continuing the discussion of retarded development, he says:

In the case of our blister-beetles, depending as they do on locust eggs, and especially in the case of those which feed particularly on the eggs of migratory species, it is not difficult to perceive how this trait may prove serviceable to the species possessing it. Migratory locusts occur in immense numbers in some

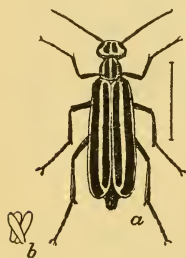


FIG. 20.—Striped blister beetle (*Epicauta vittata*): a, Female beetle; b, eggs. Enlarged. (Chittenden.)

⁶ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS. SECOND REPORT, U. S. ENT. COMM. DEPT. INTERIOR, 1878 and 1879, pp. 260-261. 1880.

particular part of the country at irregular intervals, and there are periods or years of absolute immunity from their presence in the same regions. The young blister-beetles that hatch the year following the advent of the locusts in immense numbers may frequently find few or no locust eggs upon which to prey, and the great bulk of them would, as a consequence, perish; while the young from such exceptional individuals as should not develop till two, three, or more years after a locust invasion might stand a much better chance of finding appropriate food and of thus perpetuating the species. In this case and in most other cases of retarded development with which we are familiar, the exceptional retardation may and does become a benefit to the species, enabling it to bridge over periods of adversity. And we can see how, by the preservation of such favored individuals, the habit of irregular development may have become fixed in the species as a consequence of surrounding conditions and circumstances which render it advantageous.

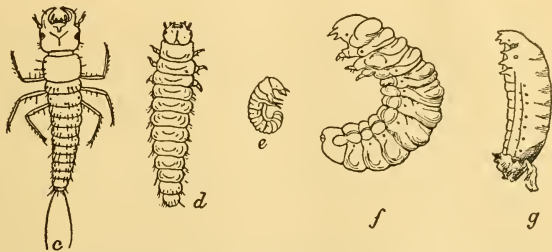


FIG. 21.—Striped blister beetle (*Epicauta vittata*): c, Triungulin larva; d, second or caraboid stage; e, same as d, doubled up as in pod; f, scarabacoid stage; g, coarctate larva. All except e enlarged. (After Riley.)

In these two paragraphs Riley points out the tendency to irregular development which is exhibited in blister beetles, and the benefit which it undoubtedly is to the species. He discusses the irregularity as a tendency which is already acquired, though indicating its origin "as a consequence of surrounding conditions and circumstances." Whether he believed that irregular development could be induced in individuals by subjecting them to certain conditions he does not state.

During retarded development the additional time involved is spent in the coarctate larva stage. Low temperature inhibits development in any stage, but in the other stages activity is resumed with increased temperature. The hardy triungulin can survive for two or three weeks without food, but Riley reports⁷ that the first molt is usually experienced about the eighth day after the first taking of food, indicating that normal development begins with reception of nourishment. Entering an egg-capsule automatically limits the food a

⁷ RILEY, C. V., PACKARD, A. S., and THOMAS, CYRUS. FIRST ANNUAL REPORT U. S. ENT. COMM. DEPT. INTERIOR, U. S. GEOL. SURVEY, 1877, p. 299. 1878.

triungulin can secure. If the eggs in a capsule fall short of the minimum requirement to carry the larva to maturity it perishes; if they exceed this minimum the difference is registered by the size of the beetle which develops. Consequently, in a given species there is great variation in size of the adults. The third larva is injuriously affected by insufficient or excessive soil moisture; however, the variation or limits in which it is safe are commonly prevalent in semiarid regions during spring and early summer. The pupæ are exceedingly sensitive, being injuriously affected by excessive soil moisture, handling, high temperature, or a soil rich in humus. Even prolonged high humidity injures them. Many on which a little earth dropped or that are exposed during an examination gradually turn dark and decay.

The coarctate larvæ, on the other hand, are resistant to handling, to exposure, to drying, or to any soil disturbance that does not crush them. They have even become overgrown by saprophytic soil fungus while in storage without loss of vitality. Excessive soil moisture, however, or continued high humidity, such as is necessary to produce conditions that favor the development of fungus, is usually detrimental. The position of the coarctate larvæ in the soil facilitates drainage, standing, as they do, on end in the old exuvium and touching the soil only in the dorsal region of the prothorax. Treatment to which they were submitted by the writer also demonstrated their ability to withstand extreme exposure and drying. Coarctate larvæ that remained for months in open containers without soil, in open containers on dry soil, and buried in pulverized dry soil have transformed shortly after being placed in moist soil.

When coarctate larvæ are very dry during the spring and early summer the rigid skin often splits immediately if water is thrown directly upon it, the larvæ emerging within a few minutes. Such dry coarctate larvæ also soon transform when placed on moist earth.

Coarctate larvæ that are kept dry during the spring and summer may or may not give forth the third larvæ when moistened in the fall. The instance cited of seven that were buried and forgotten and later found to have become third larvæ, six of which reverted to the coarctate stage, illustrates another mode of behavior of such specimens. During the time they were buried the insectary was flooded by run-off irrigation water from an adjacent field. The floor was barely covered by water and dried quickly, especially in the end where the box was buried. It is possible that enough water penetrated the box to initiate development, but not to complete it. The six larvæ that resumed the coarctate stage did so as a protective measure, or else the coming of cold weather caused this resumption. The writer attributes their reversion to one of these alternatives. Granting the correctness of these deductions, it indicates a more

complete adjustment to the semiarid conditions under which they thrive best than anything in Riley's writings that have come before the writer.⁸

An attempt will be made to apply these conclusions to field conditions as found in western Kansas: The rainfall is most abundant in spring; it gradually decreases through the summer, but increases again toward fall. The coarctate larvæ that receive sufficient moisture transform as soon as the temperature becomes favorable, and usually are able to complete their life history before the moisture becomes deficient. If for any reason—lack of rainfall, impervious soil, or deflection of rainfall by sheltering vegetation—the soil moisture is deficient, the coarctate larvæ remain dormant. If, after their appearance, the third larvæ find insufficient moisture they revert to the coarctate stage, and they may behave similarly if low temperature occurs. It is not known how long coarctate larvæ can remain dry in undisturbed cells without impairment of their vitality.

The preceding discussion of the environmental factors responsible for the phenomenon of irregular development in blister beetles is intended not only to present the author's interpretation of his data, but to direct attention to what he believes is a fertile field for research on the factors influencing insect development. The incompleteness of the data will insure the reception of this paper as a report of progress of work done during this period with the available time and material, instead of as a definite statement of results and conclusions.

CONTROL MEASURES.

While the writer was engaged in the work on life history and habits of blister beetles, tests were made of remedies whenever an opportunity occurred. The work on remedies may be considered under two heads: (1) Effect of arsenicals, contact insecticides, and repellents; and (2) control measures in infested fields.

EFFECT OF ARSENICALS, CONTACT INSECTICIDES, AND REPELLENTS.

ARSENICALS.

The widely prevalent idea that arsenicals are ineffective against blister beetles was left in doubt in the earlier tests of the poisons by the writer; the beetles would disappear, leaving but few dead ones visible. In order to learn definitely whether the beetles were killed by the poisons single beet plants were sprayed with each kind and beetles confined thereon in cages, 10 beetles being placed in each cage. The experiment was conducted three times during July, 1913, and the data are given in Tables 1, 2, and 3. The kind of poison

⁸ The writer has read only the reports of the U. S. Entomological Commission.

used is indicated at the heads of the columns, with its strength in pounds to so many gallons of water. With Paris green an equal quantity of quicklime was used.

TABLE 1.—*First experiment in the use of arsenicals, contact insecticides, and repellents against blister beetles; begun June 30, 1913.*

Date.	Number of beetles dead after spraying with—			
	Paris green, 1-1-25.	Zinc arsenite, 1-20.	Lead arsenate, 1-12½.	Bordeaux mixture, 4-4-50.
July 1..	0	0	0	0
2..	6	3	0	0
3..	10	8	0	0
4..	-----	10	0	0
5..	-----	-----	0	0
7..	-----	-----	5	1

When the experiment was discontinued the beet sprayed with Bordeaux mixture was defoliated with only one beetle dead, and the one sprayed with lead arsenate was badly damaged with only five of the beetles dead. Lead arsenate made such a poor showing that its strength was doubled in the second experiment.

TABLE 2.—*Second experiment in the use of arsenicals, contact insecticides, and repellents against blister beetles; begun July 7, 1913.*

Date.	Number of beetles dead after spraying with—			
	Paris green, 1-1-25.	Zinc arsenite, 1-20.	Lead arsenate, 1-6½.	Bordeaux mixture, 4-4-50.
July 8..	0	0	0	0
9..	3	10	2	0
10..	10	-----	8	0
11..	-----	-----	10	3
12..	-----	-----	-----	5

The beets sprayed with Bordeaux were again badly defoliated, but the increased strength of lead arsenate prevented much damage.

TABLE 3.—*Third experiment in the use of arsenicals, contact insecticides, and repellents against blister beetles; begun July 22, 1913.*

Date.	Number of beetles dead after spraying with—			
	Paris green, 1-1-25.	Zinc arsenite, 1-20.	Lead arsenate, 1-10.	Bordeaux mixture, 4-4-50.
July 24..	1	0	1	0
25..	3	2	1	2
26..	7	5	2	2
28..	10	7	4	7
29..	-----	10	6	8
30..	-----	-----	7	8

During these experiments Paris green has, except in one instance, killed the beetles in less time than zinc arsenite. Its killing time has been consistently shorter throughout than lead arsenate in quantities that it is practicable to apply. The results from Bordeaux mixture do not justify its use in this connection. Of the beetles poisoned during these experiments very few remained in sight. Most of them were to be found among the bases of the stems or under clods about the base of the plant.

REPELLENTS.

To determine what substances possess the greatest repellent properties, part of a cluster of beet plants was sprayed with Paris green, part with Bordeaux mixture, part with fish-oil soap, part with nicotine sulphate, and the remainder with water. A large screen cage was then set over the beets and about 70 beetles introduced. They scattered over the plants indiscriminately, but none fed on the ones treated with Paris green and Bordeaux. A little foliage was eaten from the plants treated with nicotine sulphate and soap. The beets sprayed with water were defoliated.

CONTACT INSECTICIDES.

Lime-sulphur in strengths up to 30 per cent did not produce satisfactory results. The weaker solutions had no effect on the beetles and the stronger ones stunted the beets.

Whale-oil soap, 1 pound to 2 gallons of water, killed beetles that could be thoroughly wet, but injured both sugar beets and potatoes on which the applications were made. No other contact insecticides were tested.

CONTROL MEASURES IN INFESTED FIELDS.

On June 23, 1913, blister beetles attacked a half-acre field of sugar beets at the Garden City branch of the Kansas Experiment Station. Most of them were the small-spotted blister beetle (*Epicauta maculata*), but the outbreak included a few of a large gray blister beetle or spotless blister beetle (*Macrobasis immaculata*). The little four-leaved plants had been stripped to the midribs over most of the field, and on the remainder the beetles were feeding. They were also crossing the road into a patch of Irish potatoes.

The beets where the beetles were feeding were sprayed with 1 pound of lead arsenate in 9 gallons of water. Part of the potatoes were sprayed with 1 pound of zinc arsenite in 32 gallons of water, part with 1 pound of Paris green and some lime in 40 gallons of water, and the remainder left as a check. The beets were so small and so badly eaten before being sprayed that they never recovered.

The sprayed potatoes were only slightly injured by the beetles, but the unsprayed ones were defoliated (fig. 22).

On July 5 a small patch of potatoes, grown by Dr. C. O. Townsend of the Bureau of Plant Industry for experimental purposes, was attacked by blister beetles of several species. The potatoes were being sprayed with Bordeaux mixture, so Paris green was added thereto for part of the patch and zinc arsenite for another portion. The potatoes designed to be left as a check on the Bordeaux treatment were sprayed with Paris green alone. These potatoes suffered



FIG. 22.—Field of potatoes attacked by blister beetles; strip through middle left unsprayed. Sprayed on left and on extreme right. (Photo by Lill, Bureau of Plant Industry.)

very little during the attack. Another invasion occurred three weeks later, at which time the potatoes were all sprayed with Paris green, 1 pound to 25 gallons of Bordeaux where the latter was used, and the same strength alone on the remainder. No damage resulted from the second attack.

Three acres of sugar beets belonging to Mr. D. A. Sheaks, of Garden City, Kans., were attacked by blister beetles that gathered in one edge of the field, most of them being large beetles (*Macrobasis immaculata*). On July 26 about half of the field, including the infested portion, was sprayed with $1\frac{1}{2}$ pounds of Paris green and some stone lime in 50 gallons of water. The beetles ceased their injury on the sprayed portion of the field, those that escaped collecting on beets on the unsprayed area. Not more than 25 per cent of them were killed.

On July 28 blister beetles from a freshly cut field of alfalfa gathered in a one-acre field of beets. About one-third of the patch

was sprayed, 1 pound of Paris green and some lime in 25 gallons of water being used. Another half-barrel of the solution was then prepared, the nozzles were changed for others having smaller openings, and the spraying was completed, only about a third of the second half-barrel of solution being used. The next morning dead beetles were numerous among the bases of the leaves and under clods. Those that remained alive were mostly stupid and helpless. The beetles were *Epicauta cinerea* and *Macrobasis unicolor*, which are of only medium size.

On July 25, 1914, a test was started at the Garden City branch of the Kansas Experiment Station on two tenth-acre plats that had been attacked by blister beetles to determine the comparative value of spraying and dusting. Paris green was used as a spray, 1 pound to 25 gallons of water; as a dust, 1 pound to 5 pounds of powdered lime; and lead arsenate was used as a dust without dilution. Part of each plat was treated with each formula. There was no perceptible difference in results. Of the small beetles (*Epicauta maculata*) a large percentage were killed, but of the large ones (*Macrobasis segmentata* Say, and *Macrobasis immaculata*) more escaped than were killed.

DRIVING.

When disturbed while feeding blister beetles drop or climb down rapidly to the ground and run away, sometimes traveling several yards before stopping to feed. Fields that are attacked by them may often be saved by taking advantage of this habit and driving them off. Several persons form a line and advance through the field, knocking the beetles from the plants with brooms, sticks, or pieces of brush. The advance should be slow, allowing time for killing any beetles that fall behind. At Garden City five persons in half a day drove the beetles out of 25 acres of beets. The method is to be recommended where most of the beetles are of the large varieties, where the plants are small and unable to survive defoliation if it occurs, or where for any reason immediate results must be secured. It is not practicable where abundant foliage affords concealment for the beetles.

SUMMARY OF CONTROL MEASURES.

Attacks by the smaller beetles are easily controlled by spraying with 1 pound of Paris green with lime in from 25 to 40 gallons of water. Many of the larger species are killed by the stronger solution. Dusting with 1 pound of Paris green to 5 pounds of powdered lime or with pure lead arsenate is effective against the small beetles, but can not be recommended against the larger ones. Driving the beetles out of the field is recommended wherever the work of the beetles must be checked at once.

The application of control measures for blister beetles must take into account the relation of these insects to grasshoppers. As long as the latter are present their eggs provide food for the young of the beetles. The destruction of the grasshopper eggs leaves the blister-beetle larvæ without food, thus being doubly beneficial. Incorporating into the farm practice of a community the simple measures that are known to hold grasshoppers in check will eliminate the danger from blister beetles.

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December 3, 1921

STUDIES ON THE BIOLOGY AND CONTROL OF
CHIGGERS.By H. E. EWING, *Specialist in Mites.*

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Difference in susceptibility	10		

INTRODUCTION.

Notwithstanding the obvious economic importance of chiggers, and an almost universal acquaintance with their injury, little has been done in the past to ascertain their habits in nature or to find efficient methods for their control. Because of these facts the writer decided early in the season of 1919, with the approval of Dr. L. O. Howard, Chief of the Bureau of Entomology, to begin a series of experiments and observations on their biology and control. The work was started in June of that year and continued until the fall of 1920. For various reasons it was thought advisable to discontinue the work then for some time, hence the results thus far obtained have been prepared for publication. It is the expectation of the writer, in the near future, not only to complete the life history for at least one of our species, but to give a synopsis of the taxonomy and distribution of the species occurring in the United States.

SPECIES CONCERNED.

Years ago C. V. Riley (*10*)¹ described from this country ("south-western States") two chigger species under the familiar names of

¹ Reference is made by number (*italic*) in parentheses to "literature cited," page 19.

Leptus americanus and *Leptus irritans*. Although these names have been used frequently in American literature dealing with economic entomology, and the figures of Riley's two species often copied, the present writer is bound to confess that after studying carefully Riley's descriptions and figures and some of his microscope slides (types?) he has been unable to correlate either *americanus* or *irritans* with the two species with which he is familiar. Further than this, it can now be fairly definitely stated that *americanus* is not a species of Trombidiidae at all, but is rather a species of the family Erythraeidae, a group to which the genus *Leptus* really belongs, as Riley's

figure clearly shows. *Leptus irritans* is the larva of a species of Trombidiidae, but the characters given by Riley are not even of generic value; hence it appears that it will never be known certainly what species his *irritans* is.

In New Jersey, Maryland, the District of Columbia, Virginia, and southeastern Iowa there is apparently a single chigger species. The writer has examined many specimens from these sections and finds that they are all the same.

In the northern and western part of the United States there is another very closely related species which has the body shaped exactly like the first mentioned but has more dorsal spines on the abdomen, and fewer branches or barbs on the palpal setæ. This is the species

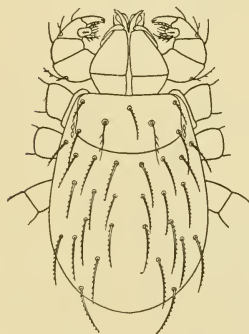


FIG. 1.—Dorsal view of an American chigger (legs omitted), X 150. This drawing was made from specimens in the University of Minnesota collection, which were taken at Lake Minnetonka, Minn.

studied by C. W. Howard (6). Specimens have been examined from Minnesota and Kansas.

NOTES ON SEASONAL HISTORY.

Chiggers are especially pests of the summer months, as has long been known, but the period of their activity has not been known, even relatively. During the year 1919, at Washington, D. C., the date of the first record of larvæ attaching themselves to man was July 2, and by July 17 larvæ were present in great abundance. On the latter date the writer was severely attacked. During the remainder of July and the whole of August the chigger larvæ continued in great abundance, and almost daily records of their attacks were obtained. In September the attacks were much less severe, yet continued. On September 22 several larvæ attached themselves to man at Chesapeake Beach, Md. No records for the northern part of the United States of chigger attacks in October have been brought to

the writer's attention, but some of the larvæ are probably active during this month.

During the season of 1920 the chiggers were first noted in southeastern Iowa on June 24, when several attached themselves at Keosauqua, where they were present in the State park.

How chiggers pass the late fall and winter is not known, and will not be known until more work is done on the life history of the species and something is known of the nymphal and adult instars.

LOCAL DISTRIBUTION.

Investigations of the last year and a half have thrown much light upon the local distribution of our chiggers, which in turn may furnish the clue for locating their natural hosts and thereby give us an opportunity to rear the larvæ to maturity.

Around Washington, D. C., the chiggers usually have been encountered where there was a heavy growth of wild brush or blackberries. They are not found in cultivated fields or where the ground is bare or in well-kept parks and lawns. Usually they are absent from meadows and from weed patches unless some kind of growth of canes or shrubbery is present. They are always encountered to some extent in woodlands, but are present in great numbers only where there is a considerable growth of underbrush.

In the State of Iowa the chiggers have an even more interesting distribution. Here whole counties in the northern part of the State are apparently free from them notwithstanding that conditions for them seem ideal. The writer has collected mites for years about Ames, Iowa, and on many occasions has made special trips in search of chiggers, but has never found a single specimen in this locality. Yet the town of Ames is almost surrounded by woods and hemmed in by two creeks, and there are situations almost exactly like those along the lower Des Moines River, where chiggers are abundant.

Judging from the records up to date, chiggers are only present along the main river courses in the south-central, southeastern, and eastern parts of Iowa. From the city of Des Moines north along the Des Moines River the writer has not been able to collect specimens, although the attempt was made in several localities.

The environment found necessary in Iowa is the same as that in Virginia or Maryland, since nearly all the land is given over to cultivation; however, chiggers are found only in a relatively small area, while in the East they are found over very extensive ones.

HABITS OF UNATTACHED LARVÆ.

The belief has been almost universal that chiggers in this country are found in the grass. Observations have failed to confirm this theory. It was found that our northeastern species occurs almost

exclusively at or near the surface of the soil. In this respect the larvæ differ from tick larvæ, which climb up on vegetation of various kinds and remain in wait for a host. People frequently get chiggers when they go into the grass, but our eastern species approaches from the ground. The mites can be found in surface scrapings, but repeated attempts to recover them from growing vegetation have failed.²

If chiggers attack man almost solely from the ground the question may be asked, How are we to account for attachments around the waist, under the armpits, and about the eyes? Again, observations show that chigger attacks are seldom made above the waistline, unless the clothes are quite loose around the waist, or the individual has been sitting or reclining on the ground. When one simply walks through a chigger-infested region, the larvæ are first found about the feet and ankles. Here they can be seen with a hand lens. They run with great rapidity, so fast in fact that it is very hard to catch them. From the ankles they spread upward, few as a rule attaching here, unless the clothing is tight; if so, many may attach. As they pass upward many of the larvæ either stop themselves or are stopped at the garters, if these are worn below the knees. If they pass the garters large numbers will attach in the space under the knees. Those that pass the knees usually go as far as the waistline before they attach.

Two factors are of importance in regard to the localization of chigger attachment—the tightness of the clothing at certain parts of the body and the thickness of the skin. The garters around the legs and the belt around the waist act as semieffective barriers. For a great many minutes, sometimes for a few hours, the larvæ run over the skin hunting a favorable place of attachment. These rapidly moving larvæ are halted by the garter or belt pressure, and after struggling some time either to pass through the mesh of the clothing at these points or to extricate themselves may attach without further search. The writer has watched these active larvæ on the skin of man before and after attachment and finds that tight clothing does not aid them in “digging in” by furnishing a fulcrum, as has been supposed. In fact, it was found experimentally that chiggers do not “dig in,” as has been so frequently stated, but remain attached externally like a tick does.

The thickness of the skin is of great importance in localizing chigger attachments. Where the skin is unusually thick the larvæ attach with great difficulty or not at all; and of those that do attach

² Dr. F. H. Chittenden has reported to the writer chigger attacks coming from overhead vegetation. The writer has never experienced such attacks, and up to the time of the preparation of this paper none had been reported to him. It may be that a second species, which is relatively rare, occurs in this vicinity, as Dr. Chittenden suggests.

many can not remain attached during the body movements of the host or are not able to reach the lymph supply of the true skin and engorge. Of the thousands of chigger attachments observed by the writer, not a single one was found on the calloused parts of the hands or feet.

HOSTS.

It was the belief of earlier entomologists that chiggers lived upon the juices of plants. That C. V. Riley shared this common belief is evident from the following statement (10) which he made in regard to one of his species:

The normal food * * * must, apparently, consist of the juices of plants and the love of blood proves ruinous to those individuals who get a chance to indulge it.

When it was learned by actual rearing experiments that several of the species of Trombidiidae were normally parasitic on terrestrial tracheates, this older theory was dropped, and it was commonly assumed, and frequently stated, that the chigger larvæ were normally parasitic on insects and closely related invertebrates. This belief was equally shared by the mite specialist and the general entomologist; but that the chigger larvæ could be normally parasitic on vertebrates was never suspected; in fact, the references to their "death feast" on man or domestic animals continued as numerous as before.

When the writer began, in the summer of 1919, his search for the natural host of the species occurring in Virginia and Maryland, he collected all insects found parasitized with trombidiid larvæ. These larvæ were examined to see if any of them belonged to the species attacking man, or were in fact true chiggers. Although many insects and other tracheates were found parasitized, in no instance did these parasitic larvæ prove to be the species attacking man.

Not satisfied with this method of investigation, another was instituted. On some vacant lots that had grown up to a considerable extent in blackberries and which were very heavily infested with chiggers (over a hundred attached in less than two hours), insects of all kinds were collected. There were hundreds of them and scores of species.

These insects were taken to the laboratory and examined both alive and after killing in cyanide bottles, and in no case was a single specimen of our eastern chigger found. The sweepings and other collections were so thorough that this observation convinced the writer that the chigger found in the vicinity of Washington is not a normal parasite on terrestrial tracheates that live above the ground.

Although never believing in the old vegetarian theory of the earlier entomologists, the writer decided to give this theory a test. First a minute examination was made of the blackberry plants, including all parts both in and above the ground. Not a single chigger was found on them. Then the examination was extended to the other plants growing on the vacant lots—goldenrod, several grasses, and a number of common weeds. Each plant species was taken by itself, specimens were pulled up, shaken over white paper, taken to the laboratory, and even examined in parts with the microscope. After several days of fruitless attempts to locate the larvæ feeding on plants the work was stopped, for evidently they could not have been feeding normally on these, or at least a few of their enormous numbers would have been encountered.

About this time there appeared in this country the extensive paper by Drs. T. Kitashima and M. Miyajima (7) entitled, "Studien ueber die Tsutsugamushi-krankheit," in which is given, among other things, a summary of the work on the life history and habits of the Japanese chigger, *Trombicula coarctata* Berlese (1). These writers claimed to have reared this chigger mite from field mice and to have established the fact that it was normally parasitic on the same. A few days later Dr. Miyajima, who happened to be visiting in this country, called at the Bureau of Entomology while in Washington. During his stay he reiterated his statement that the Japanese chigger was normally parasitic on field mice and also said he believed that it normally parasitized various other mammals.

Following the conference with Dr. Miyajima, it was decided at once to investigate the small rodents which were known to exist in the vicinity and on the ground of the infested lots. A dozen traps were procured and trapping began with these on September 13 and continued until September 24. In all, traps were set in 21 different situations, including 13 in the infested area and 8 on adjoining unfested ground. Small mammals, chiefly rodents, were caught and examined microscopically in the laboratory as follows:

September 13-----	4	September 18-----	2	September 23-----	1
September 15-----	3	September 19-----	1	September 24-----	1
September 16-----	1	September 20-----	1		
September 17-----	2	September 22-----	1		

In all, 17 small mammals were caught, all within 11 days. Among those obtained the following were determined by Dr. Ned Dearborn, of the Bureau of Biological Survey: House mouse (*Mus musculus*); common meadow mouse (*Microtus pennsylvanicus*); short-tailed shrew (*Blarina brevicauda*).

Not only were the skins of these mammals examined carefully, but the ears and some of the other parts were removed and washed violently in alcohol and the washings examined. As a result of these examinations not a single chigger was found.

This examination of the small mammals of the infested area, it should be noted, was made late in the season. It is possible that if the trapping had been done earlier, different results would have been obtained. During the summer of 1921 such trappings are planned for the months of June and July. It will be interesting to observe the results.

Among other hosts held under suspicion were reptiles. Tortoises were found in the vicinity of the infested area. These were caught and examined, but no chigger larvæ were found. Early in July, 1920, Mr. William Palmer, of the National Museum, captured a large king snake, *Lampropeltis getulus getulus*, at Chesapeake Beach, Md., that had hundreds of mite larvæ attached to its skin, between the scales. He brought the snake to the Museum, and when it was shown to the writer a few days later it had molted. In the cast skin were found hundreds of trombidid larvæ in various stages of engorgement. An examination of these showed them to be no other than the chigger that attacks man along the Atlantic slope. Parts of the cast skin with chiggers attached were placed in breeding cells, and chiggers that appeared fully engorged were likewise placed in breeding cells, but in neither case did any of the larvæ transform into nymphs.

Those attached to the skin of the snake remained attached and soon died unless forcibly removed. The actions of the chiggers in remaining attached to the skin after the latter was cast and their dying in this attached position would seem to show that the king snake is not a natural host. Further, it is known that chiggers exist in enormous numbers where very few snakes of any kind are found.

The determination of the natural hosts of our American chiggers has not been made. Further investigation along this line is needed.

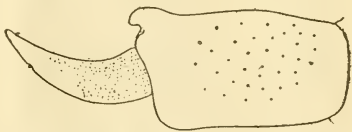


FIG. 2.—Right chelicera of a chigger-mite larva from the inside, X 1,200. Drawing made from specimen taken at Lake Minnetonka, Minn., and belonging to the University of Minnesota collection.

INJURY.

CHIGGER INJURY CONFUSED WITH MANY OTHER KINDS OF INJURY.

Of the many complaints about chiggers that have come to the writer, a very large number, fully one-half in certain sections, were found upon investigation to be due to hives, caused by the disagreement of some food eaten and probably accentuated by hot weather. A very large number of complaints supposed to be concerning chigger attacks were found to be due to nettling from some thorned plant. Serious attacks in a front lawn in Virginia, reported to be

due to chiggers, were found to be due to *Hyletastes missouriensis* Ewing, a gamasid mite, the habits of which are not well known.

Injury from fleas is very similar to the first-stage injury of chiggers, and since fleas soon leave their hosts and chiggers are so small that they frequently are overlooked, flea injury is mistaken for chigger injury. A careful examination with a hand lens will enable one to see the attached chiggers and prevent confusion of flea injury with an attack by chiggers.

DO CHIGGERS PENETRATE THE SKIN?

Both among entomologists and the public generally there is a belief that chiggers burrow into the skin. C. V. Riley (10) states in regard to his *irritans* that "This mite is able to bury itself completely in the flesh." In speaking of the same chigger, Osborn (8, p. 252) says: "It is brushed from the leaves of various plants onto the hands or clothing of people and to the bodies of other animals, and the mite then proceeds to burrow into the skin."

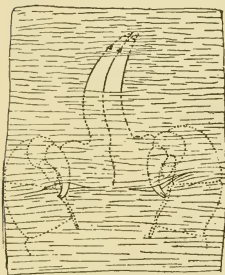


FIG. 3.—View showing the method of attachment of a chigger (northeastern species). Drawing of a part of a "slice" of skin, made from the underside while the larva was attached.

To find out whether chiggers penetrate the skin or not, and also to observe their injury, resort was made to experimentation. On July 15, 1919, the writer exposed the left calf and ankle to chigger attack, and after the mites had settled numbered 10 individuals by writing on the flesh near the mite with ink. Daily observations were made on these chiggers, using low and high power lenses, for the next eight days. It was observed on the first day that the mites attached only by their mouthparts and in no way burrowed into the skin. Observations on the second day showed no change; in fact, after once attaching to the skin by their mouthparts the larvæ became quiescent and did not change their position until they dropped off.

By means of a razor blade several individuals were removed by slicing off a small area of the epidermis around them. When this "slice" of epidermis was examined under a high-power microscope objective it showed the attachment as represented in figure 3. The hooked and ventrally barbed chelicerae were thrust into the epidermis only, and the palpal claws were found forced downward and backward into the epidermis. After both the chelicerae and the palpi have been inserted in this fashion they hold the larva locked, as it were, to the skin. This was made evident by watch-

ing the actions of larvæ with high-power objectives after they had been removed with a "slice" of epidermis. They wriggled first one way, then another, pulled with all their strength backward and forward, gave side twists, and in fact strained in almost every possible way until released. One individual was timed during this process, and it took it seven minutes to free itself from the hold it had obtained on the epidermis.

These observations were repeated upon a lot of 16 individuals for nine successive days. They were numbered as before, and daily observations made upon them. Not only did none of these larvæ burrow into the skin, but they remained attached only by their mouthparts and engorged like ticks. Later they released this hold and fell off.

DO CHIGGERS ENTER THE PORES OF THE SKIN?

Some authorities, while not believing that chiggers burrow into the skin, yet hold that because of their minute size they enter the pores and thereby cause much inflammation and other injury. This point has been carefully investigated. Of the 26 numbered individuals that were observed and studied daily, 21 were attached to the smooth surface of the skin, while 5 were attached at the bases of hairs, each having the capitulum thrust into the mouth of the hair follicle as shown in figure 4. Not a single one had penetrated a pore or hair follicle.

The species occurring in the northeastern part of the United States shows a tendency to attach at the mouth of hair follicles. It may be that the larvæ actually try to enter. They are prevented, however, from doing so under normal conditions of the skin by the small diameter of the follicles themselves.

For this same reason it would be impossible for chiggers to enter the pores of the skin, unless the latter were greatly dilated as a result of some skin trouble. In diameter the pores of the skin range from 20 to 50 μ , according to Piersol. The width of an unengorged larva from either the western or eastern part of this country is approximately 150 μ . Thus it is seen that unless the pores were unusually dilated the mites could not enter if they would.

In the case of persons who have just cleaned out the pores of the skin after a long period of negligence, it would be possible for the mites to enter some of them, as, for example, pores dilated by comedones. The writer has observed such pores dilated until they were



FIG. 4.—"Slice" of epidermis from the skin of calf of leg showing method of attachment of eastern chigger in mouth of hair follicle.

fully 400 or 500 μ in diameter. These pores, however, are most frequently on the face or neck—regions seldom attacked by chiggers. In all the observations made, including many hundred, of chigger attacks, it has always been possible during the early stage of attack to locate the chiggers themselves or their evident places of attachment, and this has always been on the surface of the skin or in the mouths of hair follicles.

DIFFERENCE IN SUSCEPTIBILITY.

Another common belief among the public and entomologists is that a great difference exists between persons in susceptibility to chigger attacks. Such a difference usually has been assumed to be physiological. Observations were made to ascertain the foundation for such a belief, if any existed. Upon several occasions it was observed that there was a difference in injury to people who apparently had all been exposed equally to the attacks of chiggers. It was found in most cases, however, that although all members went on the same picnic, or collected berries in the same patch, or made the same journey, they were not equally exposed to the attacks of the mites. Particularly three fundamental differences were found: First, a great variation in the clothing, especially about the feet and ankles; second, a variation in the actions of the persons, some never sitting or reclining on the ground; and third, a great variation in the intensity of chigger infestation even over a small area. Observations clearly show that these are usually the reasons why some members of a party are but slightly attacked while others are driven almost frantic.

Laboratory tests show that chiggers attack by preference where the skin is very thin and the flesh wrinkled or tender. Field observations also have brought out the fact that women and children suffer more from a given number of chiggers than men do. In other words, a correlation exists between thin skins and seriousness of chigger attacks. This, however, is the only way in which certain differences in the seriousness of chigger attacks between individuals equally exposed could be explained. Although hundreds of people were found susceptible to chigger attacks, no one was found who was clearly shown to be immune.

LOCAL INJURY.

Since there has been so much confusion in regard to chigger injury, a careful tabulation was made daily in the case of two lots of infestations. The first lot of 10 individuals, located on various parts of the leg below the knee, were numbered and notes made daily upon the appearance of the local area around each point of attachment, with the following results:

Attachment of chiggers followed irregularly within a few hours after exposure. The itching which appeared during the latter part of the first 24 hours following attachment grew in intensity. At 24 hours after attachment not a single papule had appeared at any one of the 10 points of attachment. During the second day swelling subsided, and the pinkish coloration around the puncture points was followed, first by a light blood-red and later by a deep blood-red color. The immediate area around each larva changed to a whitish color, and the discolored area as a whole was large and in some cases mottled with light and dark red. The itching sensation reached its maximum the second day.

During the third day after infestation most of the spots changed from the pinkish or light blood red of the second day to a dark blood-red or purplish red. At the end of the third day one-half of the larvæ had become detached.

During the fourth day few changes were noticed. One more larva had dropped off, and a few of the spots were observed to be lighter in color than the day before.

During the fifth day all the remaining larvæ dropped off. Spots retained most of their color and in four instances small water blisters developed near the center of discolored spots.

On the sixth day the color of the spots continued to fade and in one instance was practically lost.

During the seventh day several of the spots regained almost their normal flesh color. Five water blisters were observed, but only one was conspicuous.

On the eighth day the discoloration had entirely disappeared in one instance and almost so in two others. Two water blisters were left.³

GENERAL DISTURBANCES.

As has been known for many years, general disturbances frequently follow serious attacks from chiggers. Among the most serious of these is the development of a fever and a temporary upsetting of certain nervous responses. Oudemans has recently called attention (*11, p. 10*) to the narrative of Alfred Russel Wallace relative to the latter's experience with chiggers in the Malay Archipelago. This eminent naturalist wrote:

All the time I had been in Ceram I had suffered much from the irritating bites of an invisible acarus, which is worse than mosquitoes, ants, and every other pest, because it is impossible to guard against them. This last journey in the forest left me covered from head to foot with inflamed lumps, which after my return to Amboyna, produced a serious disease, confining me to the house for nearly two months * * *.

³ The appearance of these water blisters is well illustrated by Riley and Johannsen (*11, fig. 43*).

In this country Prof. Herrick (4, p. 317-325) has made observations on chiggers in various parts of the United States. He says:

Very often a slight fever accompanies the eruptions and the patient is liable to lose sleep and suffer almost unbearable torture.

In regard to the general disturbances caused chickens the same authority states (5, p. 258-260):

The chicks seem to contract a diarrhea, grow weaker and weaker, and finally die.

Where the attacks from chiggers are slight, as a rule, no general symptoms are produced. When there is a sudden attachment of several hundred larvæ general symptoms may result. The irritation produced by such a large number may prevent sleep for several nights in succession and thereby upset or disturb digestion. Also, a peculiar nervous disturbance may be caused. This may be brought about by toxins injected by the larvæ or by some other cause.

During the months of July, August, and September, 1919, the writer on many occasions was attacked by chiggers. Some of these attacks were severe and on more than one occasion blood-red spots larger than a half dollar were left. As a result of these repeated attacks a peculiar nervous effect was produced. During parts of the day a feeling of lethargy was noticed, yet to many things a hypersensitiveness was produced. This irritable state became so pronounced at times as to make productive work all but impossible. With this upsetting of the nerves, interference of bodily processes was observed to a considerable extent. It was only after the cool days of November that a normal condition was restored.

RELATION TO DISEASE.

Until the work was begun in Japan on the cause of flood or river fever ("tsutsugamushi-krankheit") some 15 years ago, chiggers had enjoyed an almost complete freedom from suspicion as actual disease carriers. As the work on this deadly disease progressed, however, they were soon held to be implicated in some way and finally shown to be the active carriers of the virus of this disease.

The results of various Japanese workers show that this disease is caused by a nonfilterable virus which is transmitted by means of the chigger bites to man. The natural reservoir is apparently the normal hosts of the chiggers, chiefly field mice, as only a small percentage of the larvæ are infected. Kitashima and Miyajima (7, p. 232) state that while "tsutsugamushi-krankheit" is similar to typhus fever and Rocky Mountain spotted fever in that the virus is nonfilterable and arthropod-borne, yet the disease itself is quite different from either.

River fever is a very deadly disease, as about one-third of all the cases are fatal. The only regions of the country affected are those along the water courses or in lowlands. Various attempts have been

made to discover and work out the development of the causative organism, but to no avail.

Among the various substances that have been employed in medication in connection with the disease the following have been used with negative results: Quinine, iodine, quicksilver, arsenics, and staining preparations. From the beginning to the subsidence of the fever salvarsan and trypan red have been used with very poor results. An attempt has been made experimentally to utilize a serum for the disease, but without results.

As chiggers are parasitic only in their larva stage and do not change hosts, it appears that the causative organisms must be transmitted from larva to nymph, to adult, thence to egg and to larva again. Such a development, although a little unusual, already has a near parallel in the case of the protozoan *Piroplasma bigeminum*, the organism of Texas fever, which is transmitted from mother to egg to larva or to nymph, in its alternate host, the North American fever tick, *Margaropus annulatus* Say.

In view of what is already known in regard to the transmission of river fever, the biology of the chigger mites, and the general symptoms following their serious attacks on man and domestic animals, the writer now predicts that in the next 50 years other serious diseases will be shown to be transmitted by these acarids. Should these mites become the transmitters of fatal diseases of domestic animals on a large scale it would be found that the protection of cattle or sheep from them would present a very difficult problem, as the mites are so minute and so widely distributed in woodlands and along water courses.

CONTROL.

In the case of man much protection can be had from chigger attacks by properly clothing the lower extremities or by the application of repellents either directly on the skin or on the under garments.

PROTECTION AGAINST CHIGGER ATTACK.

Since the unengorged larvæ are not over 150 μ in width, it is seen that they can pass through the mesh of many kinds of garments; it is easy, however, to wear those of a weave tight enough to prohibit the larvæ from passing directly through the cloth. The employment of tightly woven cloth, or other materials which are impervious to the larvæ, nevertheless, is not enough. These garments must be worn so as to fit tightly around the edges or the larvæ will yet have an avenue of entry.

It was frequently noticed that half-shoes exposed the ankles, and for that matter indirectly the whole body, to much more serious

⁴ The control of chiggers affecting poultry is considered in Farmers' Bulletin 801. The measures given in the present bulletin have reference more particularly to chiggers as parasites of man.

attacks than topped shoes. This the writer demonstrated himself many times. High-top shoes or, better yet, laced boots, gave a considerable amount of protection. On several occasions the writer was accompanied on his trips by Mr. W. W. Diehl, of the Bureau of Plant Industry. Mr. Diehl demonstrated well how the body could be protected by wearing topped shoes and spiral puttees. The latter were wrapped tightly about the calves and gave almost complete protection.

Concerning this method, however, there are two objections: First, it causes a considerable discomfort to wear such tight and rather heavy clothing during the hot season, and second, if the individual sits down, reclines, or brings the hands in frequent contact with the surface of the ground, the chiggers will attack in considerable numbers.

Another method of gaining protection which has been tried in the past is to use some repellent on the skin or on the clothing. Sulphur has long been recommended for this purpose and Dr. Chittenden (2, p. 5) calls it "a sovereign remedy for mites." A test of its efficacy was made as follows:

At East Falls Church, Va., on July 25, 1919, before going into a well-known infested area, the left stocking and the lower part of the underwear on the left leg were dusted inside and out with flowers of sulphur. The sulphur was applied by the "pinch method," followed by rubbing. About a tablespoonful was used. From 2.30 p. m. to 4.20 p. m. there was exposure to attack in the infested area, and at the end of this time a laboratory examination was made. On the calf and ankle of the untreated leg several chiggers were observed, all unattached and running about very energetically. On the calf and ankle of the sulphured leg not a single chigger was found. Later, at 9.45 p. m., another examination was made. The untreated leg had a large number of chiggers attached, these being distributed from the ankle to the hip. The treated leg did not have a single chigger attached.

On August 4, 1919, a test was made to see if a dusting of sulphur on both sides of the clothing was any more efficacious than dusting on one side only. The stocking and underwear below the knee on the left leg were sulphured by the "pinch method," both inside and out. The stocking and underwear below the knee on the right side were sulphured as before, but only on the outside.

At 3.30 p. m., after exposure, an examination of both legs failed to reveal a single chigger. It was noticed also that there was much more sulphur adhering to the left leg than to the right. A later examination at 11.30 a. m. the next day failed to reveal a single chigger on the left leg and only one chigger wheal on the right, this being near the instep of the foot.

It would appear from this that the dusting with sulphur inside the hosiery and underwear is sufficient if it is so applied as to be well distributed. Later tests fully demonstrated that a single application was sufficient if well distributed.

The "pinch method," i. e., applying a powder insecticide by picking up small amounts with the thumb and fore finger, while well adapted for dusting lousy chickens, for example, was observed to be both tedious and wasteful, hence other methods were resorted to.

Application by means of a talcum shaker was made on August 9, 1919, followed by exposure at Vienna, Va. Examination that night showed it to be 100 per cent effective.

On August 15, 1920, application was made with a pepper shaker. A considerable tendency of the sulphur to clog the small holes of the top was noticed, but by violent agitation a fairly even application was made. Only the inside of the stockings and the lower part of the underwear were treated. Exposure for about 3 hours was made in the woods north of Chesapeake Beach, Md. Later examination showed 100 per cent efficiency. It should be added that if sulphur is dusted by means of a salt or pepper shaker, after the operation all unused sulphur should be removed and the container washed. This will prevent the tarnishing of the metal parts of the shaker.

Mr. Flint, of the State Natural History Survey of Illinois, states that he has applied sulphur by means of a small bag and also by the "pinch method," with good results. Dr. J. W. Folsom also reports good results from sulphur treatment by the "pinch method." During the summers of both 1919 and 1920 several members of the bureau staff tried the use of sulphur, and in every case good results were reported and usually complete protection.

DESTRUCTION OF BREEDING PLACES.

It is hoped that the observations made on the habits and local distribution will enable much more to be done to advantage in destroying the breeding places of chiggers. Especially is this method of attack to be recommended about private dwellings and in poorly kept public parks and at summer resorts. Already its feasibility has been demonstrated. In and around Washington many chigger-infested lots or fields have been automatically rendered free of chiggers by turning these to cultivation or cleaning away the rough growth. Prof. F. L. Washburn (12) has the following to say in regard to the effect of cutting down bushy growth in Minnesota:

Capt. Zimmerman, living on Enchantment Island, Lake Minnetonka, having found this pest troublesome on his own island and upon the neighboring Phelps Island, has reduced their numbers materially by cutting out much underbrush, thus letting in the sunlight.

A well-known golf course was laid out west of the District of Columbia in a region heavily infested with chiggers. Later an investigation showed that the sodded areas where the balls were played were quite free from chiggers. When persons went into the patches of rough growth between or around these areas they were attacked by chiggers.

A chigger-infested lot in East Falls Church, Va., was cleared of rough growth and a house put on it during the summer of 1919. These operations destroyed the breeding places of the chiggers.

Of all the growths that favor the harboring of chiggers none is more favorable than wild blackberries or wild dewberries. Wild blackberry patches in Virginia and Maryland invariably were found to harbor immense numbers of chiggers. Where such patches are located at very objectionable places their obliteration would seem justified. The fruit produced by these wild canes is of a good quality, however, and constitutes not a small item in the summer food supply of the country; hence a wholesale destruction of wild blackberries would be both rash and foolish.

Dr. Chittenden has mentioned (2) the value of cattle and even of the passing of many persons in destroying chiggers. In 1914 (3) he published the results of a conversation which he had with Mr. William N. Irwin (through an error given as E. F. Erwin), who before his death was connected with the Department of Agriculture; in this conversation Mr. Irwin stated that he considered cattle inadequate where a large area was to be dealt with. He claimed, however, that he had experienced good results where sheep were used instead of cattle. The efficacy of sheep in chigger eradication thus being shown, an explanation of their agency and its effect on the chiggers is due. Dr. Chittenden claimed that the value of cattle in chigger control came from the trampling of the pests, and he would explain in the same way the benefits from the utilization of sheep, adding, however, that the sheep are probably more effective, by "keeping the grass more tightly cut than would cattle." Mr. Irwin explained the agency of the sheep as being due in part to the ascent of their legs by the chiggers and their destruction through contact with the oil in their wool. The present writer would explain this observed difference between the efficacy of cattle and sheep as being due chiefly to the food habits of the latter, the sheep not only keeping the grass more closely cropped, but also feeding to a considerable extent on the leaves of shrubbery.

Just what the value of a certain amount of shrubbery is to chiggers is not known in the case of our species. It may furnish a favorable environment for the natural hosts of the parasites, or furnish the necessary environment for either the nymphs or adults of the chiggers, or both these instars, or furnish a proper environment for the larvæ.

It has been stated that the cropping or mowing of grass lets in more sunshine and in this manner destroys the chiggers. This can hardly be the case, however, as larvæ have been handled and exposed frequently in the bright sunshine and no ill effects to them noted. In the field also, where there is only a scant growth of dewberries and an abundance of sunshine chiggers may be found in great numbers.

Chiggers are almost semiaquatic and will endure frequent submergence. In the laboratory they do well, if not their best, in an atmosphere near saturation. This humidity requirement will help explain the advantage of a rough growth to the species, which lives almost exclusively at the surface of the ground. In most situations it may be that the moisture is only sufficient when the ground is clothed with a considerable growth of vegetation. Thus the effect of sunshine would appear to be indirect and to destroy the chiggers in most situations where allowed to act by drying the surface of the ground.

DESTRUCTION OF THE CHIGGERS THEMSELVES.

It is stated that chiggers may be destroyed by a liberal application of sulphur to the field. The use of 50 pounds to the acre has been recommended. For this purpose a dust gun or dust blower could be used to advantage. On lawns the use of sulphur is unnecessary, as chiggers will automatically disappear if the grass is kept cut short.

Chiggers may best be destroyed on the body of man before they become attached or very soon afterwards. If one knows that there has been exposure to chigger attacks the shins and ankles should be examined with a hand lens for the active larvæ even before any itching sensation is felt. Only a few of the active larvæ will be observed. They will be seen to run over the skin very rapidly and can not be captured to advantage.

Larvæ on the body can be easily killed by the application of an acaricide. Various substances applied at the time of bathing have been recommended. On August 10, 1919, after exposure to chigger attacks, a thick lather of soap was applied to the affected parts. The lather was allowed to remain for 10 minutes and was worked continually over the skin. After 10 minutes it was washed off. Examination next day failed to reveal any chiggers and no itching developed.

On August 18, 1919, after exposure at Somerset, Md., and after larvæ had attached, the same application of thick soap lather was tried. On the 19th much itching was felt, yet no chiggers were found. Apparently the soap had acted as an acaricide but not as a palliative.

Dr. Maurice C. Hall, of the Bureau of Animal Industry, reports excellent results from the use of sulphur ointment against the larvæ after they have become attached.

Commercial alcohol (95 per cent) has been used by several acquaintances and by the writer himself to good advantage against the chiggers attached to the skin. When the free larvæ are immersed in alcohol and observed under the microscope they are seen to die in short order, usually in from 1 to 3 minutes. The alcohol is an excellent acaricide and also a good antiseptic for the unabraded or slightly abraded skin, and has a further advantageous effect in hardening the dermis. It should be applied quite freely and the application repeated two or three times.

Any of the lighter oils kill the larvæ quite rapidly, and can be used to advantage against the larvæ if the latter are confined to a small area on the body. Sulphur acts slowly, but if applied with soap and allowed several minutes to act should give good results.

PALLIATIVES.

To those who go little afield and are thus ignorant of some of nature's ways warnings that preventive measures should be taken are usually but little heeded, hence it is necessary to give directions in the use of palliatives—the most unsatisfactory of all measures. Undoubtedly most of the so-called palliatives are of value chiefly, if not entirely, because of their acaricide action or because they act antiseptically, or in both these manners.

In the Panama Canal Zone, according to Dr. W. A. Taylor, Chief of the Bureau of Plant Industry, a saturated solution of salicylic acid in alcohol, with a little olive oil added, has been used to good advantage as a palliative. Both he and Mr. H. H. Bennett, of the Bureau of Soils, used this mixture with very beneficial results in the Canal Zone.

In the Southern States, according to Mr. Bennett, butter or lard with a liberal mixture of table salt, or pure kerosene oil, is frequently used as a palliative. With regard to their benefit he says: "I am still not convinced that they are more than moderately efficacious * * *."

Among the other substances recommended as palliatives are the following: Ammonia, cooking soda, dilute solution of iodine, camphor, and alcohol. Statements made to the effect that an acid toxin is injected by the larvæ are not based on observed fact or experimental demonstration. We do not know even that a toxin is injected by these acarids. As before stated, the intelligent use of palliatives awaits experimentation on the nature of chigger injury from the physiological standpoint.

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A. C. TRUE, Director.



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PROFESSIONAL PAPER

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HEAT PRODUCTION OF HONEYBEES IN WINTER.

By R. D. MILNER, *formerly Assistant Chief of the Office of Home Economics, States Relations Service*, and GEO. S. DEMUTH, *formerly Apicultural Assistant, Bureau of Entomology*.

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Studies of the behavior of honeybees in winter¹ show that these insects do not hibernate, but throughout the entire winter they consume their stores of honey and generate heat. The results of these studies further show that after the winter cluster is formed, at 14° C., there is an inverse relationship between the temperature inside and outside the cluster, and that the generation of heat to warm the winter cluster is solely by muscular activity, such as fanning of the wings and other movements. These results do not agree with the conclusions of Parhon² that the honeybee is in part heterothermic. The work on behavior of the bees during winter, from which the practical conclusions as to the needs of bees in winter were drawn, was chiefly on temperature responses, and no data were available as to the actual heat production of the bees during this season. The work herein recorded was begun in order that the missing data might be in part obtained.

From many observations it has long been known that the duration of life of the individual worker bees is determined by the work which

¹ U. S. Dept. Agr. Bul. 93 (1914), *The Temperature of the Honeybee Cluster in Winter*. By Phillips and Demuth. See also Farmers' Buls. 695, 1012, and 1014.

² Parhon, Marie, 1909. *Les échanges nutritifs chez les abeilles pendant les quatre saisons*. Paris: Masson et Cie. 57 pp.

they are called upon to do. When there is a heavy honey flow and the bees are at their greatest activity their lives are limited to about 6 weeks, while during the winter season, if every condition is favorable, they may live 6 months. On the other hand, it is clear from the experience of beekeepers and from the investigations previously mentioned that if the conditions in wintering are unfavorable the bees are aroused to great activity. Under these conditions they are greatly reduced in strength, and even though they may live through the actual period of winter, they are so depleted in vitality that they are unable to do the heavy work incident to building up the colony to full summer strength, and they die off faster than their places are taken by the emerging bees of the brood reared in the spring. In the honeybee organism either the power of constructive metabolism is entirely lacking or it is far less effective than that of destructive metabolism, and the rate of the latter is apparently accelerated by the activity of the bees, thus bringing on more rapidly the impairment of functional capacity which ends in death. The physiological changes which occur in worker bees during this process of aging are not well understood, but certain facts have been observed which are significant. Mr. Goodrich-Pixell³ has found that the nerve cells in bees dying of exhaustion are highly vacuolated and the cytoplasm greatly depleted, thus substantiating the work of Hodge⁴ and of Smallwood and Phillips.⁵

Chief among the factors that influence the activity and consequent welfare of a colony of bees in winter are the condition of the colony at the beginning of winter (physiological age of the individuals), external temperature, quality of the food used during confinement, ventilation, humidity, and various causes of irritation. The experiment here recorded was undertaken to study the responses of bees to some of these stimuli, as measured by heat production, being a continuation of the work of Phillips and Demuth (*loc. cit.*) on the behavior of bees in winter, in which work the temperature responses were of greater significance. It was carried out in December, 1915, and the intention was to continue with similar experiments in other seasons under a wider variety of conditions than was maintained in this instance. Such investigations can be conducted only after brood rearing has normally stopped, and they must be concluded before the bees are filled with feces, in order that the data may not be complicated by activity due to this disturbing factor. It is therefore

³ Quart. Jour. Micros. Sci. [London], n. ser., 64 (1920), No. 254, Pt. 2, pp. 191-206. ill. Determination of age in honeybees.

⁴ Jour. Physiol., 17 (1894) Changes in ganglion cells from birth to senile death; observations on man and honeybees.

⁵ Jour. Comp. Neur., 27 (1916). Nuclear size in the nerve-cells of the bee during the life-cycle.

possible to carry out but one experiment a year with a given colony. Circumstances incident to the war prevented continuation of this work, but the results obtained in this experiment are of such economic importance, as well as scientific interest, that it seems desirable to publish them without further delay.

SOURCE OF HEAT IN THE WINTER CLUSTER.

The effect of external temperature on the activity of a colony of bees is conspicuous. The bee is similar to other cold-blooded animals in that it lacks the means for internal regulation of body temperature that are found in birds and mammals, and hence the temperature of its body is affected by that of the surrounding air. As the temperature of the air in the hive falls in winter the bees become less active until a certain critical temperature (14° C.) is reached, at which they undertake by muscular activity, not unlike that of shivering, to produce heat in order to keep warm. Between the combs and sometimes extending above or below them they form an approximately spherical and fairly compact cluster, with the bees on the outside comprising a sort of shell with their heads turned toward the center. This shell may be several layers thick, the number of layers and the compactness of the cluster depending upon the size and condition of the colony and the temperature of the air in the hive. The bees in this shell remain quiet, except for an occasional shifting of position, but those in the space inside the shell become very active, moving about, shaking their bodies, and fanning vigorously with their wings, thus producing heat to warm the cluster.

By means of many thermocouples fastened in different parts of the hive Phillips and Demuth (*loc. cit.*) were able to measure the temperatures at various points within and around the winter cluster. They found that when the temperature of the air within the hive and surrounding the bees was between 14° and 20° C. the bees remain quietly on the combs but not clustered, their body temperatures being, of course, approximately that of the surrounding air. While the upper temperature limit of this quiescent condition is not definitely fixed, varying with the condition of the bees and the weather outside the hive, the lower limit is quite accurately determined by the needs of the bees. When the air temperature falls to 14° C. the bees come together to form the winter cluster. If the temperature falls still lower, they begin to generate heat within the cluster, and frequently the inner temperature rises considerably above those temperatures at which the bees were able to exist without activity. Temperatures as high as 30° to 35° C. are not uncommon, and, indeed, were observed even when the air outside the cluster was as low as

0° C. In locations where the outer temperatures fall much below this the bees are still able to maintain high temperatures, more bees taking part in heat production. That such high temperatures can be maintained in these circumstances indicates that the shell of bees is effective as a heat insulator, but there is obviously a serious drain on the vital capacity of the bees employed in producing heat. This is shown by the rapid slowing down of the fanning of the wings as it continues.

OUTLINE OF THE EXPERIMENT.

To obtain information regarding the actual amount of work done by a colony of bees while in the winter cluster, a small colony on four combs having natural honey stores was placed in the chamber of a small respiration calorimeter and their carbon-dioxid production and oxygen consumption were measured for 10 days, while the temperature of the air surrounding the bees was kept just low enough so that the bees at all times would remain clustered. Throughout the experiment the temperature of the air surrounding the bees and at several points within the cluster was taken in order that this work might be made comparable with the work on the behavior of bees in winter as indicated by temperature responses. The bees were located in a box within the calorimeter so constructed that while they could not escape from it there was opportunity for abundant ventilation. There were 14 thermocouples distributed in the hive in the calorimeter in such manner that the temperatures in different places inside and outside the cluster could be ascertained, the leads from the thermocouples being extended through the outlet in the wall of the chamber to a potentiometer on the outside. The temperatures were read every half hour, day and night, for nearly 12 days.

The thermocouples were so placed in the hive as to make it impossible for the clustered bees ever to occupy space in which some of the thermocouples were not located, thus insuring that the temperatures of the cluster might be obtained wherever the cluster might move in the hive. The temperatures of all parts of the hive outside the cluster could also be obtained by the arrangement of these thermocouples. One of the thermocouples (No. 15) was located outside the hive and 2 inches from it, thus giving the temperature of the air of the chamber at this point. The readings obtained with this thermometer are plotted in the charts on pages 15 to 18. A resistance thermometer was also placed in the chamber, but at some distance from the thermocouple. Measurements made with this thermometer are shown in the table on page 8. The two records did not always exactly agree because the thermometers were not together.

DISCUSSION OF THE TEMPERATURE RESPONSES IN THIS EXPERIMENT.

The colony used in the experiment here reported was taken to Washington from the suburbs some time prior to the beginning of the experiment. The bees were placed in the calorimeter and then it was found that the apparatus was defective and it was necessary to remove them. During the interval before the experiment here recorded was begun, they were placed outside where they were free to fly when the weather permitted, and they had several flights and carried out the dead bees. They were therefore in good condition at the beginning of the experiment.

For several hours after the hive was again placed in the respiration chamber, the temperatures of the hive and bees were high, chiefly as a result of the disturbance arising from the handling necessary at this time. They were put in place at 3 p. m. on December 11, and during the night the temperature of the bees on one occasion, and in one point only, rose to 35° C. During the night the temperature of both the chamber and the bees drifted down, until shortly after noon on the 12th, when they may be considered as having reached normal quiescence. Just when the bees definitely formed a winter cluster is not clear from the data, but certainly when they had reached quiescence they were clustered.

In the graphic charts of temperatures of this colony, records are included for thermocouples 6, 7, and 12, these being the ones which were in the center of the cluster, which was located near the top and slightly to one side of the hive. For comparison with these the record for thermocouple 15 giving the temperature of the air of the chamber at one point outside the hive is also included.

It will be observed that on several occasions the temperature of the center of the cluster (which shifted between thermocouples 12 and 7, according to the movement of the cluster during the experiment) rose somewhat abruptly but temporarily, not, however, reaching the temperatures observed at the time that the bees were placed in the chamber. While some of the rises may be attributed to mechanical disturbances, it was not always possible to determine the exciting cause. This is in accordance with numerous observations made in the work on the behavior of bees in confinement to which reference has already been made. Throughout the experiment, of course, heat production never ceased, and with the bees in this condition of activity it took but a small disturbance to induce them to generate slightly more heat. This is comparable with the periods of activity that have long been observed in bees wintered in cellars.

It is more important to note that during the 12 days that the bees were in the respiration chamber the temperature of the cen-

ter of the cluster gradually rose from an average of 16° C. on December 13 to an average of 30° C. on the 22d, though the air outside the hive kept in the range of temperature from 6° C. to 9° C. This is in agreement with results obtained by Phillips and Demuth (*loc. cit.*) with bees wintered in a cellar which were interpreted as indicating that such an upward drift of temperature of the colony during confinement is the result of irritation because of an accumulation of feces. In the case of the colonies recorded in an earlier publication,⁶ one colony showed a slower rise than was found in this colony, while another, wintered on honeydew stores, showed a more rapid rise. Since it has been shown that disturbance of any sort causes a rise in cluster temperatures, it is not entirely clear to which disturbance the rise of this colony should be attributed. Of course, as this colony was located in a respiration chamber in a busy laboratory, it was exposed to greater disturbance than would have been the case in some other experiments or in the average bee cellar, although all practicable precautions were taken to avoid jar and the apparatus was cushioned. It is not improbable that the sudden and temporary increases in temperature may have been due to physical disturbance and that the cause of the continued rise was physiological disturbance.

It will be noted that beginning at 6.30 p. m. on December 22 the temperatures of the cluster began to drop. At this time the carbon-dioxid content of the air in the chamber was high and the oxygen deficient, as will be explained later. Under these conditions the bees were more quiet (generated less heat) than when under conditions which would usually be considered more favorable. The temperature of the center of the cluster dropped until it reached 23° C. The reason for the decrease in activity at this time has not been discovered. It was thought that the bees were dying because of unfavorable atmospheric conditions, but at 5 a. m. on the 23d the temperature again began to rise and continued until it again reached 34° C. Whether this increase in activity was a reaction in response to physical disturbance or to change in atmospheric conditions made at this time (see p. 13) is not clear.

METHOD OF MEASURING THE WORK DONE BY THE CLUSTER.

At noon, December 12, measurement of the metabolic activity of the bees was begun. The respiration calorimeter used for this experiment has been described in a publication of the department,⁷ but to aid in explaining the conditions of the experiment the principles of

⁶ U. S. Dept. Agr. Bul. 93. The Temperature of the Honeybee Cluster in Winter.

⁷ Jour. Agr. Research [U. S.], 6 (1916), No. 18, pp. 703-720.

the apparatus may be briefly summarized. The respiration chamber in which the hive was inclosed was ventilated by withdrawing air from the lower portion, passing it through sulphuric acid to remove water vapor and through soda lime to remove carbon dioxid, and returning it to the upper part of the chamber. The increase in the weights of the sulphuric acid and the soda lime during a given period indicates respectively the quantities of water vapor and carbon dioxid removed from the chamber. These represent the quantities produced during the period when due allowance is made for change in the water vapor and carbon-dioxid content of the air as ascertained from analyses made at the beginning and end of the period. Oxygen to replace that removed by the bees was supplied to the chamber from a cylinder, the gas being introduced at a rate sufficient to maintain a certain volume in the system, as indicated by a tension equalizing device which served to keep the air in the chamber at the same barometric pressure as that of the laboratory. The quantity of gas admitted was ascertained from the loss in weight of the cylinder or by reading a meter through which the gas was passed. This showed the quantity of oxygen consumed by the bees when correction was made for change in the residual oxygen content of the air of the chamber. In making these corrections for variations in residual gases, changes in temperature and barometric pressure of the air of the system were also taken into account. By proper attention to these means of ventilation, any desired conditions with respect to water vapor, carbon dioxid, or oxygen content of the air could be maintained.

The temperature of the air surrounding the hive could also be controlled to a certain extent. In a space adjacent to the metal walls of the respiration chamber, and protected by a thick heat-insulating cover, were means for heating and cooling the walls; also within the chamber was a coil of copper tubing through which cold water could be circulated to take heat from the air about the hive. By weighing the water flowing through this coil and measuring its increase in temperature, the quantity of heat carried out could be ascertained, which, with necessary corrections for heat from other sources, would be that imparted to the air by the bees.

RESULTS OBTAINED IN THE EXPERIMENT.

Data indicating the physiological activity of the bees are summarized in the following table with others showing the experimental conditions.

Summary of experimental data.

Date.	Temperature of air in the chamber.	Humidity of air in chamber.	CO ₂ in air in chamber.	Oxygen in air in chamber.	Water vapor taken from the air.	Carbon dioxid produced.	Oxygen consumed.	Heat generated.
	° C.	Per cent.	Per cent.	Per cent.	Grams.	Liters.	Liters.	Calories.
Dec. 13.....	7.3 to 8.8	.....	0.53	15.2	17.1	9.6	.....	.....
Dec. 14.....	6.4 to 8.0	75 to 90	1.42	16.8	3.4	10.4	.....	.....
Dec. 15.....	6.1 to 8.2	77 to 90	.87	17.1	5.0	11.7	.....	.....
Dec. 16.....	6.3 to 7.0	77 to 95	.81	21.1	8.1	13.3	.....	.....
Dec. 17.....	6.3 to 7.6	72 to 93	1.08	22.6	8.3	12.8	.....	.....
Dec. 18.....	7.8 to 9.2	76 to 95	.52	24.5	6.9	12.1	.....	.....
Dec. 19.....	7.1 to 7.8	50 to 86	.63	26.4	26.5	12.9	.....	.....
Dec. 20.....	6.9 to 7.9	49 to 66	.23	28.9	25.9	14.5	.....	.....
Dec. 21.....	6.8 to 8.3	47 to 66	1.40	24.5	22.2	11.0	.....	.....
Dec. 22.....	7.4 to 7.7	45 to 65	.51	18.2	23.2	16.3	.....	.....
Dec. 23.....	7.6 to 8.8	50 to 55	.29	7.3	15.9	14.9	.....	.....
Total, omitting first day						129.9	138.4	683

With the warm conditions prevailing in the laboratory, the cooling capacity of the apparatus, which had been constructed for work at higher temperatures, was not sufficient to chill the hive as much as had been desired when this experiment was planned, consequently the bees were not subjected to very low temperatures. Those shown in the table were measured with an electrical resistance thermometer suspended in the air above the hive, which was as warm as that in any part of the apparatus, but the readings on two thermometers in other parts of the chamber did not differ materially from these. The figures shown are the lowest and highest temperatures observed each day, but there was no uniformity in the time at which these occurred. The fluctuations in temperature are shown in the curve for thermocouple No. 15 on pages 15 to 18. The maximum range, from 6.1° to 9.2° C., was in the vicinity of the temperature which beekeepers usually consider favorable for bees wintering in cellars.

The daily production of carbon dioxid shown in the table is an index of the amount of work performed by the bees. This quantity was derived, in the manner previously explained, from the weight of the carbon-dioxid absorber, which was taken every 24 hours. Any error in these figures, with the possible exception of those for December 21 and 22, which are explained later, is believed to be of small magnitude. The most significant error that could occur would be due to the fact that the circulation of air was not directly through the hive, but through the chamber in which the hive was inclosed. In some cases there might be an accumulation of carbon dioxid in the hive in one period which would escape in a later period, with a

corresponding error in the measurements of the quantities for the two periods; but as there was free space in the small experimental hive for only a few liters of air, a relatively large change in the carbon-dioxid content of the air in the hive would introduce only a very small error in the quantity measured in any period.

The determination of the carbon-dioxid production for the experiment as a whole is accurate. In footing the total the quantity for the first day is omitted, because the oxygen consumed was not measured that day. In the 10 days the bees produced 130 liters of carbon dioxid and consumed 138 liters of oxygen. The corresponding respiratory quotient is 0.94, which indicates that their metabolism was almost entirely that of carbohydrate. Their heat production, calculated from these data, was 688 calories. The quantity of heat measured by the calorimeter was larger than this, but it involved an error due to leakage of heat through the walls, owing to the wide difference between the temperature of the air in the chamber and that in the laboratory, which the apparatus as used could not overcome. Making such allowance for this error as was indicated by subsequent test of the apparatus under somewhat similar conditions, the corrected amount of heat measured was but slightly different from this computed value.

The number of bees in this colony, by actual count, was 9,635. The average weight of empty worker bees is about 0.075 gram; their total weight, in round numbers, would be 720 grams. The heat output of this colony, 688 calories, was therefore equivalent to 0.97 calorie per gram for the 10 days, or virtually 0.1 calorie per gram per day. This is equivalent to a heat output of 7,000 calories per day by a man weighing 70 kilograms (154 pounds), which is found only in unusual circumstances. The average individual of this size actively engaged in hard work at least 8 hours a day would give off about 4,000 calories in 24 hours. The heat output of lumbermen working hard in the northern woods in a cold winter was found to be about 7,000 calories per man per day, as indicated by their food consumption. During the period that they were working hardest their hourly expenditure of energy may have been double the average for the rest of the day, possibly as high as 600 calories per hour, although this seems doubtful. In certain experimental conditions a well-trained man engaged in muscular activity sufficient to cause a heat output of 650 calories per hour, which was measured in the same manner as the heat output of the bees was measured in this experiment, but this was considered to be severe, exhausting work, almost at the limit of human endurance, and was continued only for short periods. This output, per unit of weight, would be larger than that of the colony of bees taken as a whole, but it will be recalled that the bees actually

engaged in the excessive activity of heat production at any one time are only a small part of the total colony, the rest of them being crowded together in the shell of the cluster or in empty cells of the honey comb or standing quietly. The amount of work done by the bees that are really active is comparable with that done by the man in unusual conditions, and is therefore relatively enormous; and this is maintained not only for short periods but through the whole day and the whole winter.

Moreover, it will also be observed that the temperature conditions during this experiment were those in which bees are the least active. In fact, as mentioned previously, the temperature in the respiration chamber during the experiment was about the same as that which beekeepers usually maintain in cellars for wintering bees. Colonies wintered outdoors, especially if unprotected, must endure in many cases much more severe temperature conditions. Furthermore, this experiment was conducted at a time of the year when bees are naturally more nearly quiescent. Bees are usually more active during the latter part of winter than during late fall and early winter. The figures obtained in this experiment, therefore, represent about as low an expenditure of energy as is ever found in a colony of bees, except for short intervals. In a preliminary test with this colony the quantities of carbon dioxid measured were decidedly larger than these, owing to less favorable conditions.

A hygrometer suspended in the chamber was read at frequent intervals. The maximum and minimum readings for each day are shown in the table. During the first five days the humidity was allowed to remain at a high level. This was accomplished by keeping the air of the system in circulation only part of the time, virtually every other hour. During the other five days the humidity was kept much lower by maintaining a constant circulation of air through the sulphuric acid. There was a very noticeable difference in the quantities of water vapor removed from the chamber in the several days of the two periods, owing to the fact that the relative dryness of the air in the later period was causing a loss of water from the wood of the hive. No difference in the activity of the bees that could be ascribed to the difference in water-vapor content of the air was noticeable in the temperature curves or in the carbon-dioxid output of the various days.

The barometer was read at noon each day. There were no significant changes in barometric pressure during the course of the experiment. The reading on the 13th was 755 millimeters, which rose each succeeding day to 769 on the 16th, then fell to 750 on the 18th. It was 767 on the 19th and for the rest of the experiment remained within 4 millimeters of this pressure.

There was no apparent effect on the activity of the bees from variations in the carbon-dioxid content of the air in the hive, at least within very wide limits. One column in the table shows the percentage of carbon dioxid in the air at the time the residual analysis was made each day. These figures tell little of the condition of the air at any other period during the day; they merely show what it was after the air of the chamber had been passing through the soda lime for at least an hour; but unless the bees had been actually more active at the time the residual analysis was made (which, according to the thermocouples, did not occur in any instance) there must have been at least as much and probably more carbon dioxid in the air previous to the time of the analysis than is indicated by these figures. It would appear, then, that throughout the whole of the experiment the carbon-dioxid content of the air in the hive was appreciably greater than that of normal air, which is probably the usual condition in a hive; also there were outside variations in the proportion of this gas in the air, as shown by the data in the table. On December 21 and 22 arrangements were made to insure a considerable excess of carbon dioxid in the air. During most of the time on these days the soda lime was removed from the train for purifying the circulating air and the carbon dioxid was allowed to accumulate within the respiration chamber while the water vapor was removed. Starting with the content of nearly one-quarter of 1 per cent on the 20th, or almost eight times that in normal air, the increase continued until in the whole air system of the apparatus, which was about 170 liters, there was included over 10 liters of carbon dioxid before the period ended on December 21, a proportion more than 200 times that in normal air. There is no significant change in the curves on page 18 showing the behavior of the bees, to indicate that they were materially affected by these abnormal conditions. The curve for thermocouple No. 7 continued at the same level for nearly 12 hours, then began to rise slowly; those for Nos. 12 and 6 fell somewhat for about 12 hours and then maintained a level for the remainder of the period. There would appear to be on the whole a quieting of the bees for this day, but this could be hardly attributed to the quantity of CO_2 present, for on the following day, when there was a still greater concentration, the activity of the bees increased.

From the character of the curves in these two days it would be expected that the carbon-dioxid production on the 22d would exceed that of the 21st, but not necessarily by nearly 50 per cent as shown in the values in the table. It is not unlikely that some of the carbon dioxid measured on the 22d was produced on the 21st. Unintentionally, replacement of the soda lime in the air circulating system was delayed until one hour before the close of the first period, and

this was not sufficient time to remove all the carbon dioxid from the system, as was shown by the high percentage of the gas found in the residual air. It is possible that in this circumstance the air in the hive had a larger percentage of carbon dioxid than that of the sample analyzed. On the 22d the air was passed through the soda lime for nearly three hours prior to the end of the period, in which case the air in the hive had greater opportunity to become like that of the system. Even with a carbon-dioxid content of at least 6 per cent, which was the case on the 21st, the quantity of the gas carried over in the hive to the next period would be much less than 1 liter, which would still leave a wide difference between the figures for carbon-dioxid production in these two days. There is nothing in the data at hand to suggest a reason for this difference. It is interesting to observe that the total of carbon dioxid produced for these two days was almost identical with that of the two days preceding them, when the carbon-dioxid concentration of the air was low.

The proportion of oxygen in the air at the end of each period is also shown in the table. These figures simply show the condition at a given time each day, but they give no definite idea of the proportion of oxygen in the air during the whole day. This would vary hour by hour with the admission of oxygen, the absorption of water vapor and carbon dioxid, and with changes in the temperature of the air, but on the whole would be somewhere in the range between the proportion at the end of one period and that at the corresponding time in the period preceding or following. The figures therefore show that there was a continual increase in the proportion of oxygen from the 13th to the 20th, then a decrease to the 23d.

The low proportion of oxygen in the air at the beginning of the experiment was due to the fact that air rather than oxygen was supplied to the system to replace the carbon dioxid and water vapor removed during the preliminary period and to maintain a sufficient quantity of air in the system while the apparatus was being chilled before the experimental conditions were established. After the experiment began, replacement was made by oxygen until the 20th, when the requisite volume was again maintained by admitting air, in order to reduce the proportion of oxygen in the air of the system. No effect that could be ascribed to changes in the oxygen content of the air was observed until the last day of the experiment. On that day not only water vapor and carbon dioxid, but oxygen also was removed from the system by passing the circulating air through a solution of potassium pyrogallate before returning it to the chamber. This was continued until the proportion of oxygen in the air, which was only 18 per cent at the beginning of the period, was very greatly reduced. After a few hours the circulation of air was stopped and the water vapor and carbon dioxid allowed to ac-

cumulate in the air of the system in which there was a deficiency of oxygen. The effect on the activity of the bees was soon apparent; the temperature curves, which for some reason had begun to rise, very shortly turned in the opposite direction and continued to fall for about 12 hours. The proportion of oxygen was then 12 per cent and it was thought that the bees had probably been suffocated. Eight hours before the time at which the period would regularly end the air of the system was again put in circulation and water vapor and carbon dioxid removed, oxygen being also removed at the same time. This was continued until the close of the period (which was also the end of the experiment) in order that the air of the system might be quite thoroughly freed of carbon dioxid. After the circulation of air was resumed the bees again indicated that they were living, and during the time that the air-purifying system was operating their activity increased until by the end of the experiment the temperature curve had reached as high a point as at any time during the course of the experiment, even though the proportion of oxygen in the air was low. Analysis of the sample taken at the end of the period showed only 7.3 per cent of oxygen.

If the decrease in the activity of the bees in this instance was due to atmospheric conditions in the hive, the cause was probably excess of carbon dioxid and water vapor rather than deficiency of oxygen. Though the proportion of oxygen in the air was decreased from 18 to 12 per cent in 16 hours, it is doubtful if this alone would have an appreciable effect upon the physiological activity of the bees. In experiments with men in atmospheres about as deficient in oxygen as this, there was no noticeable effect upon their metabolism. In these experiments, however, there was no such excess of carbon dioxid and water vapor as in the experiment with the bees.

It is possible, as intimated on page 6, that the reason for the increase in activity of the bees after the circulation of air was resumed may have been physical disturbance. Since it was thought that the bees were dying, movement about the laboratory was somewhat less restricted when the air-circulating device was started, although care was still taken to avoid jarring the calorimeter. The circulation of air through the calorimeter could hardly have caused any disturbance of the bees, because the low rate, while sufficient to keep the air in motion, could not produce any current that would stir the hive. It is also possible that, since the removal of oxygen from the air was continued during this period, the proportion of oxygen in the air eventually became so low that the bees had to respire more rapidly to obtain a sufficient quantity of this gas. It would be expected, however, that this effect would be manifested somewhat later in the period than the time at which activity was renewed.

In considering the circumstances on this last day of the experiment with bees it is interesting to recall observations made in the study of the effect of ventilation on men, that the sensations produced by "bad" air are not experienced when the air is stirred. If this indicates an actual difference in physiological conditions in the different circumstances, then it is not inconceivable that something analogous to this was true of the bees on this day. The stirring of the air when the circulation was resumed may have served to remove some cause of depression that was effective when the circulation was stopped.

SUMMARY.

In the colony of bees under observation in the respiration chamber the expenditure of energy was reduced to the lowest limit by the maintenance of favorable temperature and by the avoidance of all disturbing factors, so far as possible. Under these circumstances, rarely found in the apiary, the energy produced by the bees, as measured by the carbon dioxid and water produced and the oxygen consumed, was greater, according to body weight, than that produced by a man when working at hard manual labor, when we take into consideration the fact that the work was done by only a relatively few of the bees in the cluster. Even assuming that the work of the period were equally divided among the bees, their energy output per unit of body weight is higher than that of the average laborer. When we take into consideration the fact that usually the bees do not have such favorable conditions in winter as these bees had, it is clear that the energy output is enormous in the average apiary.

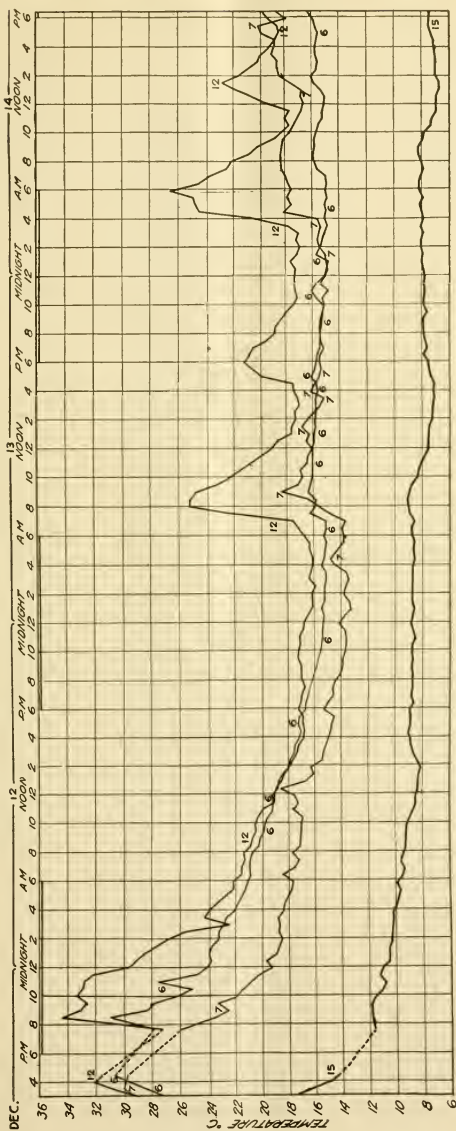


CHART I.—Temperatures shown by thermocouples 6, 7, 12, and 15, from 3 p. m., December 11, to 6.30 p. m., December 14.

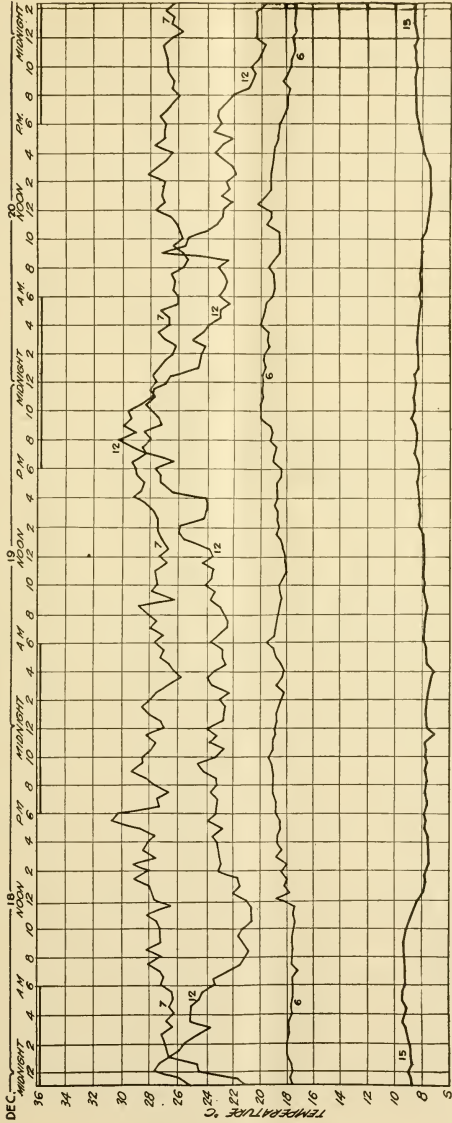


CHART III.—Temperatures shown by thermocouples 6, 7, 12, and 15, from 10.30 p. m., December 17, to 2.30 a. m., December 21.

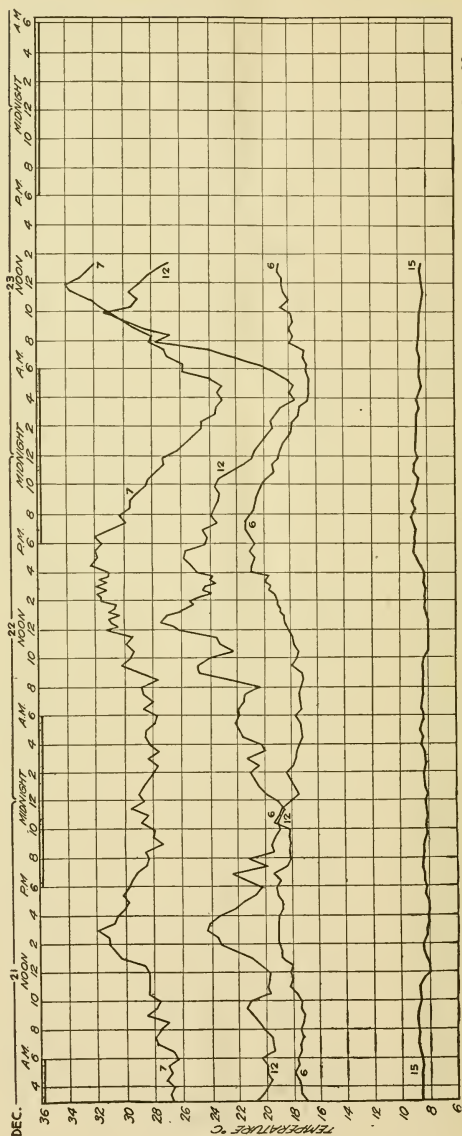


CHART IV—Temperatures shown by thermocouples 6, 7, 12 and 15, from 2.30 a. m., December 21, to 12.30 p. m., December 23.

BULLETIN No. 992

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.



November 4, 1921

WALNUT HUSK-MAGGOT.¹By FRED E. BROOKS, *Entomologist, Fruit Insect Investigations.*

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INTRODUCTION.

The larva of the walnut husk-maggot has long been known to persons who in autumn have engaged in hulling the nuts of our native black walnut (*Juglans nigra*). Soon after the nuts drop, a large percentage of them are frequently found with the hulls blackened and slimy within and containing multitudes of whitish maggots which move actively through the soft pulp. Such infested nuts are disagreeable to handle, and in hulling the husk sticks to the inner shell, leaving it dirty and unattractive in appearance (Pl. IV, *d*). Inasmuch as the fruit of the black walnut was not important commercially in the past this insect did not attract especial attention, and very few persons, even of those who were familiar with the maggots in the walnuts, ever saw the parent fly. If seen, it was probably seldom regarded as being in any way connected with the disgusting

¹ *Rhagoletis suavis* Loew; order Diptera, family Trypetidae. A closely allied species, *Rhagoletis juglandis* Cresson, has been recorded as attacking the nuts of *Juglans rupestris* and *J. regia* in Arizona and Texas. Several members of the same genus have attracted considerable attention in North America on account of the destructiveness of the larvæ to various kinds of fruit. *R. pomonella* Walsh, known commonly as the apple maggot or railroad worm, is an important pest of apples in the northern part of the United States and Canada. Two species, *R. cingulata* Loew and *R. fausta* O. S., attack cherries over practically the same region, while *R. ribicola* Doane frequently injures currants and gooseberries in the Northwestern States.

condition of the nuts. It was not until an interest developed in certain places in the East in growing the Persian or English walnut (*Juglans regia*) commercially that a demand arose for information regarding this pest. When the Persian walnut trees planted in the East began to fruit, these maggots attacked the nuts and practically ruined very promising crops in several localities. The injury to Persian walnuts and the fact that the eastern black walnut, one of the favorite food plants of the species, is becoming of increasing importance from the standpoint of nut production, have led to the investigation described herein. The project is not yet completed, but the outstanding features of the life history and habits of the insect are now known. Further studies of the species, particularly along the lines of control, are under way.

BRIEF DESCRIPTION OF INSECT AND INJURY.

The adult of the walnut husk-maggot is a two-winged fly about the size of the common house fly. The flies appear on the walnut trees at the time the nuts are approaching maturity and lay clusters of white eggs in punctures made in the husk with their sharp ovipositor (Pl. III, *e*) or in breaks which they may find in the husk of the nuts (Pl. II, *b*, *c*, *d*). Apparently no eggs are deposited in the nuts after they drop. The eggs soon hatch and the resultant maggots rapidly convert the green tissue of the husk into black pulp. After attaining full growth the maggots enter the ground and pupate, there being only one generation of the flies annually.

SYNONYMY.

The following data covering the synonymy of the species were furnished by Mr. B. A. Porter, of the Bureau of Entomology:

Trypeta suavis Loew, 1862, in Monogr. Dipt. N. Amer., pt. 1, p. 75.

Acidia suavis Loew, 1873, in Monogr. Dipt. N. Amer. pt. 3, p. 235.

Rhagoletis suavis (Loew), 1899, in Coquillett, Jour. N. Y. Ent. Soc., v. 7, p. 260.

DISTRIBUTION.

This fly probably occurs pretty generally over the natural ranges of the black walnut and the butternut (*Juglans cinerea*). In 1862 Osten-Sacken² gave its distribution as the "Middle States." In 1902 Babb³ reared the fly from black walnut at Amherst, Mass. Washburn,⁴ in 1905, listed the species among the flies of Minnesota;

² LOEW, H. MONOGRAPHS OF THE DIPTERA OF NORTH AMERICA (ed. by R. Osten-Sacken), pt. 1, p. 75. Washington, D. C. 1862.

³ BABB, G. F. NOTE ON RHAGOLETIS SUAVIS LW., WITH A DESCRIPTION OF THE LARVA AND PUPARIUM. In Ent. News, v. 13, no. 8, p. 242. 1902.

⁴ WASHBURN, F. L. DIPTERA OF MINNESOTA. . Minn. Agr. Exp. Sta. Bul. 93, p. 118. 1905.

and Banks,⁵ in 1912, reared flies from butternuts at Plummerville Island, Md. There are specimens in the United States National Museum from West Willow and Allegheny, Pa., and Dr. J. M. Aldrich, of the Museum, has in his personal collection specimens from Blue Ridge Summit, Pa., and La Fayette, Ind. During the present investigation the writer has collected or otherwise obtained specimens from the following localities: Boston, Mass.; Wallingford, Conn.; Lockport, N. Y.; West Willow and Washington Heights, Pa.; Columbus, Ohio; New Windsor, Md.; Washington, D. C.; and French Creek and other localities in West Virginia.

FOOD PLANTS.

The walnut husk-maggot has been known to attack commonly the husks of the black walnut (*Juglans nigra*) and the butternut (*J. cinerea*). The writer has reared adults from the husks of the Persian walnut (*J. regia*) and Japanese walnut (*J. sieboldiana*). Of the foregoing hosts the black walnut and Persian walnut are preferred to the others, probably on account of the thicker husks.

DESCRIPTION OF LIFE STAGES.

THE EGG.

The egg (Pl. II, *b, c, d*) is white, banana-shaped, distinctly curved, 0.9 to 1 mm. in length by 0.2 mm. in width, one end tapering gradually to a rounded point, the other end tapering more abruptly and ending in a minute but distinct spur or pedicle. The eggs are placed in masses compressed closely together (Pl. II, *b, c, d*) in oviposition punctures extending 2 mm., more or less, beneath the skin of the nuts. The female will oviposit freely in any fresh puncture which she may find in the skin made otherwise than with her ovipositor. Small punctures made experimentally in the husk with a sharp point usually were found promptly by the females and filled with eggs. In some cases such punctures would be packed with eggs and the flies would continue to oviposit on the surface until a small mound of eggs covered the opening in the skin (Pl. II, *d*). One artificial puncture in a black walnut was found to contain 186 eggs and several punctures made with the ovipositor were found to hold upwards of 60 eggs each. The eggs apparently hatch in from 7 to 10 days.

Oviposition takes place only in the green part of the husk, but after the maggots hatch and begin to feed the point of attack soon shows as a black spot on the surface (Pl. IV, *a*). This spot increases rapidly in size as the burrows of the maggots penetrate the tissues

⁵ BANKS, NATHAN. THE STRUCTURE OF CERTAIN DIPTEROUS LARVÆ WITH PARTICULAR REFERENCE TO THOSE IN HUMAN FOODS. U. S. Dept. Agr., Bur. Ent., Tech. Ser. Bul. 22, p. 32. 1912.

beneath. Persian walnuts on the trees will often turn black from this cause during a period of only a few days. Quite often the first external evidence of the feeding of the larvæ within a nut will be a slight seepage of dark juice from the oviposition wound, which will flow down and stain the skin of the nut (Pl. IV, *b*).

THE LARVA.

The larva, or maggot (Pl. II, *e, f*; Pl. IV, *c*), is white or creamy white, and is not stained by the dye-like, semiliquid matter in which it feeds. The dark-colored contents of the alimentary canal, however, give to the immature maggots a brownish appearance. When full grown they average 10 mm. in length by 2 mm. in width. The maggots are active and move about rapidly, using in locomotion their two anal hooks. They often remain in the walnut husk until severe freezing weather occurs, but take advantage of warm periods in the late autumn to leave the nuts and enter the ground a short distance for pupation.

THE PUPA.

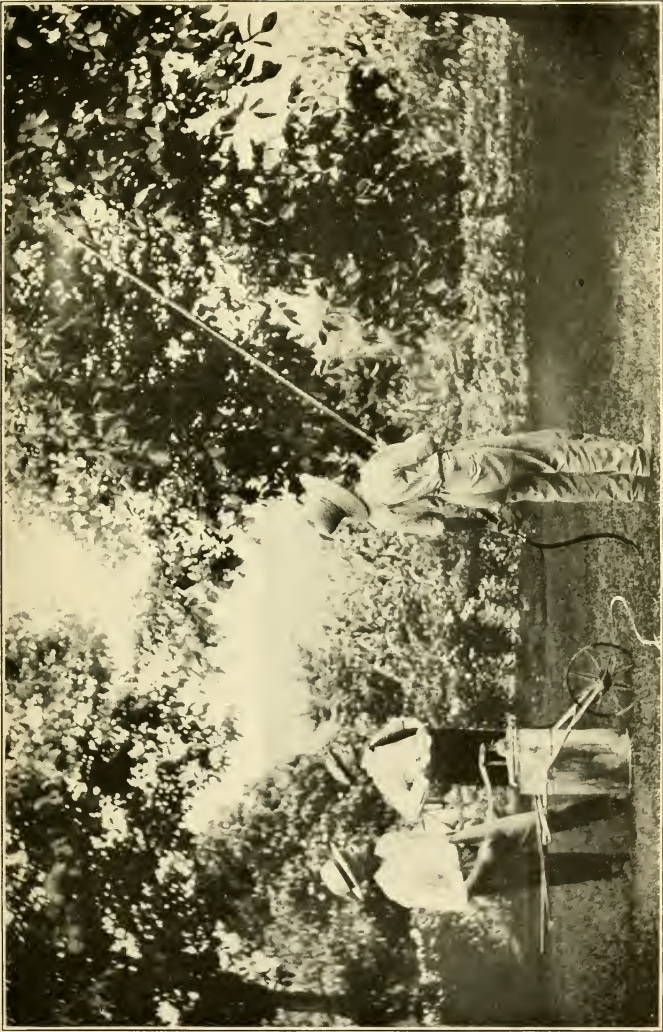
The pupa (Pl. II, *g, h*) is formed by the shrinkage of the larva and is pale yellow, cylindrical, tapers slightly from the middle toward the ends, and is 5 mm. in length by 2.5 mm. in width. There are 11 plainly visible segments, the intersegmental grooves being shallow but distinct. Each end bears a pair of small, brownish tubercles and there is a rough, brown spot near one end where the larval head was retracted. In size, shape, and color the pupa resembles a grain of wheat (Pl. II, *h*). The pupæ are formed in the ground, anywhere from half an inch to several inches beneath the surface, and the winter is passed in this stage. Most of the flies issue the following summer, but a few pupæ hold over the second winter and the adults appear therefrom during the succeeding summer.

THE ADULT.

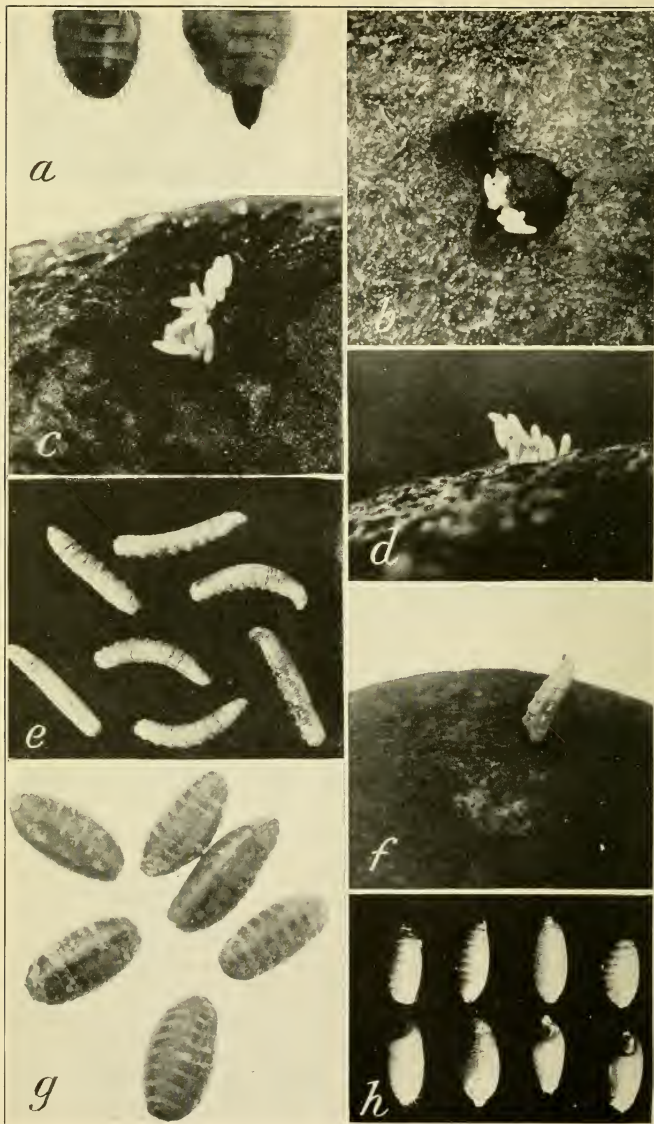
The adults of this insect vary considerably in size but average about 7 mm. in length. With the exception of the eyes, heavy wing markings, anterior margins of the abdominal segments, and bristle-like hairs, all of which are dark brown, the color is pale yellow. There is a lighter longitudinal line on each side of the thorax and the dorsal surface of the thorax is densely clothed with very short, yellowish hairs interspersed sparsely with long, stiff, dark-brown bristles. The head, sides, upper surface of the abdomen, and legs are covered more or less heavily with brown hairs. (Pl. III.)

ACTIVITIES OF THE FLIES.

The flies begin to issue from the ground at least as early as the middle of July in the latitude of West Virginia. In 1920 at French

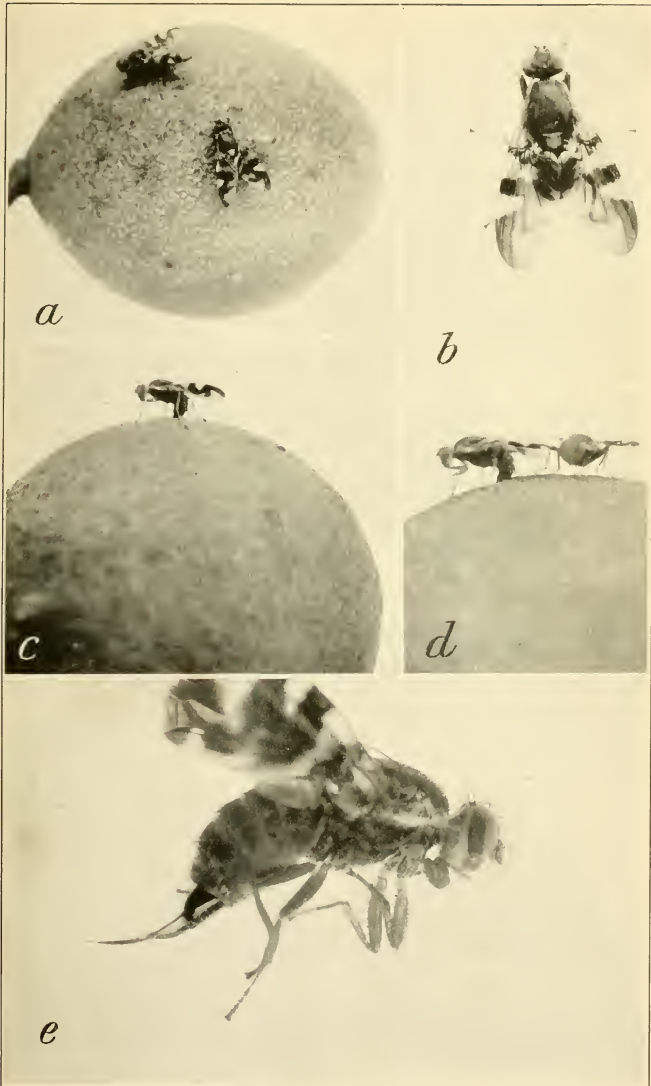


SPRAYING WITH LEAD ARSENATE TO CONTROL THE WALNUT HUSK-MAGGOT IN THE PERSIAN WALNUT GROVES OF J. G. RUSH,
WEST WILLOW, PA.



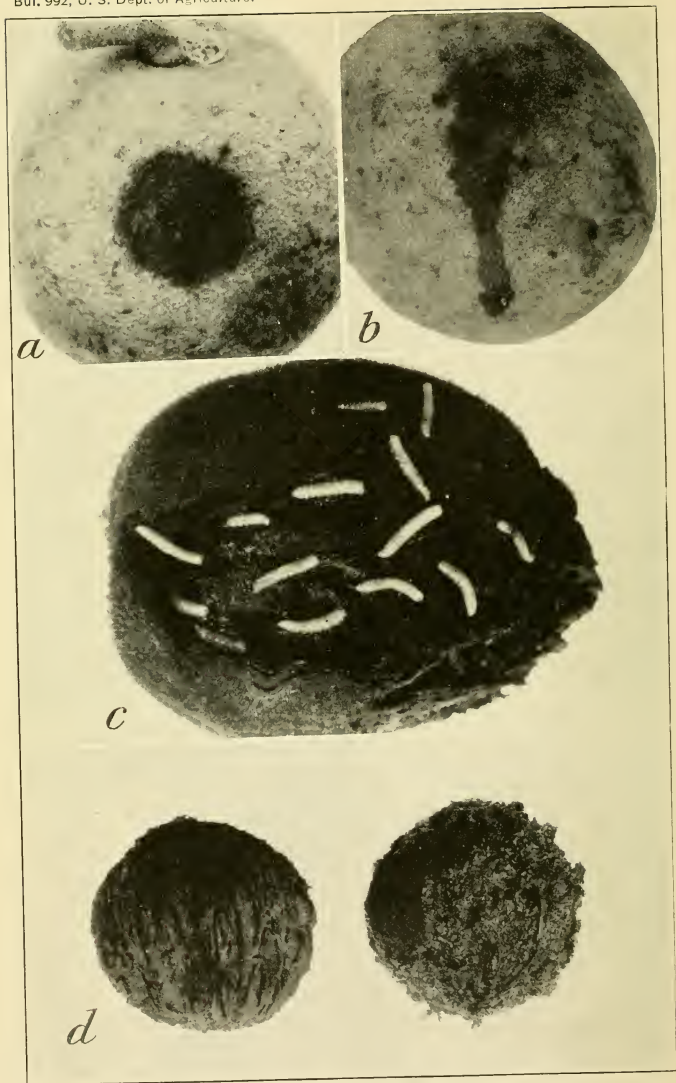
THE WALNUT HUSK-MAGGOT.

a, Genitalia of male and female husk-maggots, male on left; *b* and *c*, egg clusters in black walnuts exposed by cutting away the skin; *d*, egg cluster partly on the surface of black walnut; *e*, larvae; *f*, larva escaping from a black walnut; *g*, pupae; *h*, resemblance of pupae, above, and grains of wheat, below. All enlarged.



THE WALNUT HUSK-MAGGOT.

a, Flies of husk-maggot on black walnut; *b*, fly of husk-maggot much enlarged; *c*, female in the act of depositing eggs in a black walnut; *d*, female laying eggs and guarded by a male; *e*, female with ovipositor extended. All enlarged.



THE WALNÚT HUSK-MAGGOT.

a, Black walnut showing discolored spot on skin made by husk-maggots mining within; *b*, black walnut stained by juice flowing from oviposition scar; *c*, husk-maggots in Persian walnut; *d*, black walnuts with husk removed to show difference in hulling between sound and infested nuts; nut on the left sound, on the right infested. All about natural size.

Creek, W. Va., the first flies appeared in rearing jars on July 16, and on August 5 the first specimens were recognized definitely on the trees. Flies, apparently of this species, were seen on trees in both West Virginia and Pennsylvania several weeks earlier, but no specimens were captured and identification was not definite. Flies in rearing jars issued from July 16 to September 8, emergence covering a period of 55 days. Table I shows the time of emergence of 40 individuals in rearing jars.

TABLE I.—*Emergence of flies of walnut husk-maggot in rearing jars at French Creek, W. Va., in 1920.*

Date	Number of flies.	Date.	Number of flies.	Date.	Number of flies.	Date.	Number of flies.
July 16....	1	July 31....	1	Aug. 15....	3	Aug. 29....	0
17....	0	Aug. 1....	1	16....	0	30....	0
18....	0	2....	0	17....	2	31....	1
19....	2	3....	0	18....	2	Sept. 1....	0
20....	0	4....	1	19....	3	2....	0
21....	1	5....	0	20....	0	3....	0
22....	0	6....	1	21....	0	4....	1
23....	1	7....	1	22....	0	5....	0
24....	0	8....	1	23....	1	6....	0
25....	0	9....	1	24....	1	7....	0
26....	1	10....	0	25....	4	8....	1
27....	0	11....	0	26....	4	9....	0
28....	0	12....	2	27....	1		
29....	0	13....	1	28....	0	Total..	40
30....	0	14....	0				

Apparently flies are present on the trees several weeks before oviposition begins. At first they occupy the foliage chiefly, making short flights from leaf to leaf and resting quietly for long periods. During the preoviposition period, as well as later, they may be seen lapping at the leaves as though extracting food from deposits on the surface. As the time for the beginning of oviposition approaches the flies become more active, and both males and females show a tendency to gather about the nuts. The males habitually select certain nuts on which an individual will take his stand and often remain for hours at a time awaiting the coming of the female, combating, meantime, other males that approach. When a male alights on a nut already tenanted by another male the original occupant attacks it and usually the two rear up on their hind legs, facing each other, and engage in a brief but animated bout, belaboring each other with their forelegs. Usually the original occupant is the victor and the would-be interloper flies away.

A prick made in a walnut with a pin or other sharp point was sure to be found by a male, who, recognizing it evidently as a suitable place for the females to come to oviposit, would immediately begin standing guard over it. In one instance the writer pricked a dozen walnuts on the lower branches of a tree with the point of a small nail. Thereafter for several days a male was on guard at each of the

punctured nuts and females were observed frequently to visit these nuts, where copulation and oviposition took place. In approaching these nuts the females usually came by easy stages, flying and crawling near the nut before alighting upon it. When the male would observe a female approaching he would become much excited, moving back and forth, whirling around, and raising and lowering the wings in rapid succession, but remaining near the puncture made with the nail point. On the arrival of the female upon the nut the male would usually back away from the nail puncture a short distance and there remain stationary, with wings elevated above the back, watching the female intently. When the female would find the puncture and start to insert the tip of her abdomen into the opening for the purpose of depositing eggs, the male would spring upon her and copulation would take place. There would then follow alternating periods of oviposition and copulation, the male sometimes continuing mounted while oviposition was in progress, and sometimes dismounting but remaining near by. (Pl. III, *d.*) Frequently there would be four or five periods of each before the female would fly away. After this procedure the male was likely to continue on guard at the same place, for the nail pricks were visited frequently by ovipositing females.

The flies were observed to be much more abundant on the lower than on the higher branches of trees, and there was a great difference in the numbers of flies on individual trees of the same species. On a group of heavy-laden Persian walnut trees of the variety known as Hall, at West Willow, Pa., it was estimated that one fly was present for every two nuts on the trees. The variation in the numbers of flies on individual trees was followed by a corresponding abundance or scarcity of maggots in the nuts of each.

Flies were observed to feed upon the juice that flowed from oviposition scars and upon the naturally more or less gummy surface of the nuts. In feeding they would eject from the mouth a particle of clear liquid onto the surface and after working it over with the purselike, external mouthparts would swallow it again.

NATURE OF INJURY.

In native black walnuts the eggs of the husk-maggot fly are usually deposited so late in the season that the resultant maggots do not prevent the nuts from maturing and dropping normally. Thus, while apparently all the eggs are laid in nuts on the trees, the development of the maggots and the blackening of the husks which results from their feeding take place chiefly in fallen nuts. In Persian walnuts, however, eggs appear to be laid earlier in the development of the nuts. Bearing trees were observed in Maryland and Pennsylvania, a short time before the crop had ripened, on which

a large percentage of the husks of the nuts were blackened throughout and the surface covered with a gummy exudation from the maggot injury within. Some of the infested Persian walnuts drop prematurely and others hang to the branches until after the sound nuts have fallen. In nuts that are attacked before maturing the development is arrested and the kernel becomes unfit for use. The injury is thus threefold, in that it impairs the quality of the kernel, causes the husk to stick to the shell in the hulling process, and blackens and soils the shell, making the nuts unattractive for market.

NATURAL ENEMIES.

Only one parasite of the husk-maggot has been discovered. This is a hymenopterous species, *Aphaereta auripes* Prov., reared from the puparia by Babb (⁶) at Amherst, Mass. The writer, on September 8, 1920, found a small leaf-bug, determined by W. L. McAtee as a species of *Lopidea*, with its beak inserted through the skin of a black walnut sucking out the contents of a batch of fresh-laid husk-maggot eggs. An examination of the eggs showed that a number of them had been punctured and emptied by the bug.

METHODS OF CONTROL.

Experiments in controlling the husk maggot with lead-arsenate sprays were conducted in 1920 in the Persian walnut groves of Mr. N. H. Baile, at New Windsor, Md., and of Mr. J. G. Rush, at West Willow, Pa. Only a single application of the spray was made in each case. The grove of Mr. Baile consists of about a dozen seedling trees of various sizes, some of them about 30 years of age. At the time of the spraying all were bearing heavy crops of nuts. This grove was sprayed by means of a power sprayer on August 10, with 3 pounds of lead-arsenate paste to 50 gallons of water. The grove of Mr. Rush consists of 18 trees of named varieties, all of bearing age. The trees were producing heavily at the time the spray was applied. The spraying was done on August 9, using 1½ pounds of lead-arsenate powder to 50 gallons of water. Two trees of the variety known as Rush, three of Hall, and two of Mayette were sprayed with the lead-arsenate solution to which enough molasses had been added to give the liquid a slightly sweetish taste. For treating the Rush grove a small hand sprayer mounted on a wheelbarrow was used (Pl. I). The trees of both groves had borne the previous season, but the crops had been injured seriously by the attacks of the maggots.

At the time the groves were sprayed the adults of the maggots were appearing on the trees and a close examination of the nuts in the Rush grove disclosed one batch of freshly laid eggs. After the spraying the Baile grove was not revisited until the nuts were almost

⁶ BABB, G. F. OF CIT.

ripe. The Rush grove, however, was kept under close observation by Mr. Rush and the writer. The flies became very numerous on the trees of this grove for a period of a few days after the spray was applied and then decreased in numbers.

Examination and counts of the nuts of the sprayed trees in the Baile grove just before the crop was gathered showed that 4 per cent of the nuts had been attacked by the maggots, whereas at least 60 per cent of the crop had been destroyed by the maggots the previous year. In the Rush grove it was estimated that the condition was 75 per cent better than the year before when no treatment was given. No Persian walnut trees were found near either the Baile or Rush groves that were suitable for use in checking up definite results of the spraying. However, a comparison of the sprayed nuts with those produced by the same trees the previous season and with those produced in other localities the same season, together with the known abundance of the flies that appeared early upon the sprayed trees, indicates decidedly beneficial results from the treatment.

Flies confined in roomy wire-screen cages were observed to feed freely on sweetened water to which sufficient lead arsenate had been added to give the liquid a milky color. It must be admitted that these flies succumbed very slowly to the poison. Further tests of this treatment must be made before it can be recommended unreservedly as an effective and sure method of control for this pest.

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BULLETIN No. 1008

Contribution from the Bureau of Entomology

L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

November 15, 1921

RATE OF MULTIPLICATION OF THE HESSIAN FLY.

By W. R. McCONNELL,¹

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INTRODUCTORY AND HISTORICAL.

In the course of investigations of the Hessian fly (*Phytophaga destructor* Say) and its parasites, at the Cereal and Forage Insect Field Station of the Bureau of Entomology at Carlisle, Pa., it became necessary to have accurate data regarding the normal rate of multiplication of this insect. Such information was needed, in the first place, as a basis for estimating the efficiency of the various species of parasites. In the second place, the writer, having been greatly impressed by the rapidity with which an outbreak of serious proportions may develop in a short time from comparatively small sources, and being aware that such an increase is largely due to the reduction in effect of some of the important natural checks to the increase of the fly, suspected nevertheless that the potential rate of multiplication might be much greater than usually has been supposed.

The writer has been unable to find satisfactory data on this subject in the literature or among other recorded observations. In fact, it appears that little attention has ever been paid to the matter, especially

¹ Died June 23, 1920.

in recent times. In 1861 Wagner² by confining a female Hessian fly with wheat plants secured a total of 83 eggs. He evidently carried out other experiments, for he concludes that the number of eggs deposited by a female is more than 80 and less than 100. Koeppen³ in 1889 stated that, according to Lindemann, a female may deposit up to 200 eggs, but believed these figures too high and gave Haberlandt's statement that the female deposits only from 40 to 50 eggs.

The most careful observations up to the present time seem to be those made by Enock.⁴ He confined the female insects in cages with barley plants, securing in one case a maximum of 158 eggs. He also confined females singly in corked vials and secured in this way a maximum of 130 eggs. The number of eggs he secured by these methods ranged from 70 to 158, with an average for 10 cases of 113 eggs. He concludes that a single female lays from 100 to 150 eggs. Although Lugger⁵ dissected a female which contained 238 eggs, the usual figures given since the date of the paper by Enock are based on Enock's conclusion. This conclusion, however, resulted from an insufficient number of experiments, and the methods used in obtaining the counts will not give accurate results. The adults of the Hessian fly are extremely sensitive to conditions of temperature and moisture. The females normally oviposit at comparatively low temperatures and when moisture in abundance is present. If these conditions are reversed or if conditions are unsatisfactory in some other respect, the females will die before depositing all their eggs. A new and thorough study of the subject therefore seemed imperative.

METHODS OF INVESTIGATION.

For the reasons stated, the method of confining female Hessian flies in vials and all other methods involving their confinement in cages kept in the laboratory were rejected. Cages kept outdoors at the usual times when adults are abroad were also dispensed with, because any cage modifies natural conditions, more or less, and because it is difficult to secure accurate counts where eggs are scattered over a number of plants.

The writer is convinced that under normal conditions each female deposits practically all of her eggs. It has been found that at the time of eclosion each female contains her normal allotment of eggs in a well-developed condition; in fact, it is possible to count all of the eggs by dissecting the pupa stage. It seemed simpler and more

² WAGNER, BALTHASAR. OBSERVATIONS ON THE NEW GALL-GNAT. Fulda, 1861. Translated in U. S. Entomological Commission, Third Report. Appendix II, B, 1883, p. [15].

³ KOEPPEN, F. T. DIE SCHÄDLICHEN INSEKTEN RUSSLANDS. St. Petersburg, 1880. Translated in U. S. Entomological Commission, Third Report, Appendix IV, 1883, p. [41].

⁴ ENOCK, F. THE LIFE-HISTORY OF THE HESSIAN FLY, *CECIDOMYIA DESTRUCTOR*, SAY. In Trans. Ent. Soc. London, p. 332, 1891.

⁵ LUGGER, O. THE HESSIAN FLY. In Minn. Agr. Exp. Sta. Bul. 64, p. 552, 1899.

economical of time, therefore, to dissect the females and count the number of ova they contained, and this procedure has been followed out beginning with the fall brood of 1918.

Before the dissection of female flies and the counting of their ova had been carried very far, other difficulties appeared. These hinged chiefly on the question of what females should be counted. At first it seemed simple enough to count the number of ova contained in a given number of females and average up the results. This, however, proved to be insufficient because of the great variation in the results obtained from different lots of females. The females vary greatly in size, and, correspondingly, in the number of ova they contain; and the average number of ova per female varies in different fields.

In the study to determine some of the reasons for this condition of affairs, it became evident that the number of ova contained in a female is related to the number of puparia in a tiller. On the average, the greater the number of puparia in a tiller the smaller the number of eggs the resulting females can lay. Since the average number of puparia in infested tillers varies in different fields and in different years, the difficulty of making a fair average can be readily seen. There also appears to be a relation between the date when wheat is sown and the average number of eggs for females of the fall brood. Puparia obtained from late-sown wheat developed females with a reduced capacity for egg production. When work was begun on the spring brood in 1920 it was found that the average number of eggs varied markedly for the two principal generations. All of these conditions and undoubtedly others have to be dealt with in some manner in arriving at a fair estimate.

In view of these facts, separate counts have been made for the principal generations. In the case of the fall brood all of the puparia found in a number of plants taken from various fields were caged and every female which emerged was dissected. Most puparia were taken from fields known to be sown early and which, consequently, contained flies of all ages; or else they were taken from fields where the age of the plants was unknown. This avoided the giving of undue weight to fields sown late. In this manner many of the data accumulated have been eliminated from the general average for the fall brood.

In the case of the spring brood, all plants were obtained from a number of fields just before harvest. All their puparia were removed and caged. In two cages extremely long stubbles, which probably contained all the puparia of the original plants, were used. In this generation allowance must be made for an enormous mortality due to parasitism and weather. Usually it is not expected that more than from 3 to 10 per cent of the flies will remain alive at emergence time in the fall, and, of course, allowance must be made

for males which are sure to emerge. Taking all of these facts into consideration, success beyond expectations was achieved in the fall of 1919, in making counts for the spring brood of 1920.⁶

AVERAGE NUMBER OF OVA FOR THE PRINCIPAL BROODS.

In presenting the results of this investigation, it will be necessary to consider first the average number of ova which can be laid by females of the principal generations. The data for each of these generations will be tabulated separately. After this has been done, it will be necessary to take into consideration the proportion of the two sexes before a sufficient basis can be had for estimating the rate of reproduction of the Hessian fly.

FALL GENERATION.

In Table 1 are given the results of counting the number of ova contained in 107 females. These flies were obtained from six different fields, as indicated by their cage numbers. It will be noted that the average number of eggs per female varies considerably in different fields, even when the number of females counted is approximately the same. It is thus easy to see what a difficult matter it is to obtain a fair average number of eggs per female. The figures, however, are as fair as could be obtained for the year in question and in the time available.

TABLE 1.—Average number of ova for females of the fall generation of the Hessian fly, Carlisle, Pa., 1919.

Cage No.—	Number of females counted.	Number of ova.	Minimum per female.	Maximum per female.	Range.	Average per female.
1620.....	28	8,014	74	383	309	286.0
1716.....	26	6,148	33	365	332	236.2
1753.....	36	13,422	189	464	275	372.8
1755.....	9	1,361	107	195	88	151.2
1779.....	6	1,099	134	302	168	183.2
1795.....	2	658	314	344	30	329.0
Totals.....	107	30,702	33	464	431	286.9

The actual number of ova per female varies from 33 to 464, with a range of variation of 431 and an average per female of 286.9. It may be added that the smallest female found since this work began belonged to this brood, but to none of the foregoing cage numbers. This female was dissected by Mr. Hill, who found that it contained only 11 ova. The largest female ever found belonged also to this brood. This female was in a different series and contained 474 ova.

⁶ In this connection the writer wishes to state that two lots of females of the fall brood were dissected by Mr. C. C. Hill; Mr. P. R. Myers has determined the sex of a large proportion of the flies as they emerged, and both men have helped in collecting and caging the material. All of the work has been done in the laboratory at Carlisle, Pa., and most of the material has been collected near by.

SPRING GENERATION.

For the spring generation the ova have been counted for 160 females. The most surprising thing about the results obtained, as shown in Table 2, is the general average number of ova per female of 232.9. This is an average of 54 eggs per female less than was found in the case of the fall brood.

TABLE 2.—Average number of ova for females of the spring generation of the Hessian fly; counts made at Carlisle, Pa., in the fall of 1919.

Cage No.—	Number of females counted.	Total number of ova.	Minimum per female.	Maximum per female.	Range.	Average per female.
1841.....	57	14,591	79	386	307	256.0
1842.....	29	6,990	113	372	259	241.0
1869.....	4	780	34	297	263	195.0
1875.....	13	3,105	188	350	162	238.8
1876.....	5	836	71	255	184	167.2
1880.....	8	1,356	102	214	112	169.5
1881.....	6	1,048	100	227	127	174.7
1882.....	2	483	194	289	95	241.5
1883.....	26	5,965	116	370	254	229.4
1891.....	10	2,106	108	309	201	210.6
Totals.....	160	37,260	34	386	352	232.9

While this work has been carried through only one spring generation, it is nevertheless quite evident that this generation is constantly lower than the fall generation in its capacity for egg production. The actual minimum number of ova per female is 34, which is one more than for the fall brood. The maximum, 386, on the contrary, is much lower, and the range of variation is only 352.

SUMMER GENERATION.

While data for the flies developing in volunteer wheat are scant, the results obtained seem interesting enough to be included as Table 3. Only 15 cases are available. In spite of the low average number of eggs, this brood in all probability resembles rather closely the fall generation in the number of eggs it can lay. If this should prove true, it might be that the stage of growth of the plant has an important relation to the size of the flies developing in a plant, and consequently to the number of ova developing.

TABLE 3.—Average number of ova for females of the generation of the Hessian fly developing in volunteer wheat; counts made at Carlisle, Pa., in the summer of 1919.

Cage No.	Number of females counted.	Total number of ova.	Minimum per female.	Maximum per female.	Range.	Average per female.
1990.....	2	524	177	347	170	262.0
2090.....	13	3,027	54	448	394	232.8
Totals.....	15	3,551	54	448	394	236.7

SEX RATIO.

Before proceeding further with the discussion of the rate of multiplication, it is necessary to take up the question of the proportion existing between the two sexes. In order to acquire data on this subject, a beginning was made, more than two years ago, to record the sex of all Hessian flies that emerged in the cages. These cages contained only puparia separated from their surrounding plant tissue and reared in small vials. The puparia had been obtained in various localities in the northeastern portion of the United States. In this way the sex has been recorded of practically every fly that has emerged from a few thousand puparia each year. At the end of the first year it appeared that the percentage of females in the spring generation was remarkably high. It was not anticipated that this excess of females in the spring generation would prove to be constant, but Table 4 shows that for the second year the percentage of females dropped only slightly. Although the rearing of flies from the 1919 material has not been completed, a much larger number than usual have already been obtained, and the percentage of females for 1919 is almost the same as for the two preceding years.

TABLE 4.—*The sex ratio in the various Hessian fly generations, 1917, 1918, and 1919.*

Generation.	Year.	Number of males.	Number of females.	Total reared.	Per cent of females.
Spring.....	1917	168	276	444	62.2
	1918	146	235	381	61.7
	1919	623	1,031	1,654	62.3
Fall.....	1917	749	761	1,510	50.4
	1918	1,493	1,313	2,806	46.8
Volunteer wheat.....	1917	246	225	471	47.8
	1918	51	45	96	46.9

For the three years the average percentage of females is 62.1, and it seems quite safe to assume now that at least 60 per cent of the spring brood develop into females. In the case of the fall generation the sexes appear to be approximately equal in numbers, although figures for 1918 are rather low in females. In volunteer wheat there are a very small number of cases from 1918, but it appears in general that the sexes are about equal in the partial broods developed in the summer.

It is now evident enough that the spring brood is the one which shows the greatest variation from normal, both in the high percentage of females produced and in the reduced number of eggs these females can lay. Both may be related phenomena with a common explanation, but this explanation will have to be left to the imagination at the present time.

THE MEANING OF THESE FIGURES.

In order to demonstrate fully the meaning of the figures which have been submitted, two examples will be of considerable help.

Going on the assumption that under normal conditions practically every egg is laid, let it be assumed that none of the fly stages are destroyed by enemies. For the sake of round numbers let 285 be taken as the average number of eggs laid by the fall generation and 230 as the average by the spring generation. It may also be taken for granted that one male will fertilize several females, since Enock⁷ proved by careful methods that one male successfully fertilized as many as six females. This will take care of the preponderance of females in the spring brood.

Starting now with a single female of the spring brood emerging in the fall, it is found that she can lay 230 eggs. One-half of these eggs in the spring will produce females, each of which may lay 285 eggs. This will give 32,775 as the product of one female working through two generations in one wheat crop, with no allowance made for multiplication in volunteer wheat. The flies which develop in volunteer wheat in the East are usually comparatively small in number and are heavily parasitized. If it be assumed that all these flies remain alive in the stubbles until the next fall, there will be a total of 60 per cent of the flies emerging as females, or 19,665. If these all lay 230 eggs, there will be the enormous total of 4,522,950 flies developing in the fall wheat of the second year. The resulting females would number 2,261,475 and would give rise in the second spring to 644,520,375 fly stages. This result has been obtained in two crop years, not allowing for any multiplication in volunteer wheat.

The question may be looked at from another point of view. Probably infestation of stubbles is never as low as one puparium per acre, although the foregoing computation began with one fly. In one field studied quite carefully during the summer and fall of 1919 the stubbles were found to be infested at the rate of 4,900,000 per acre. A careful examination of the puparia in these stubbles just before the emergence season showed that only 4.4 per cent contained living fly larvae, parasites having destroyed practically all of the remainder. This 4.4 per cent amounts to 215,600 flies per acre. If 60 per cent of these were females there would be 129,360 females per acre ovipositing in the next crop of wheat and producing in it the next fall 29,752,800 ova. With similar calculations from a few other fields as a basis, a big outbreak in wheat sown in the fall of 1919 was looked for. As a matter of fact, however, it was found after the emergence season was over that many of the expected flies had failed to emerge from the stubbles. A careful count made in the field mentioned above showed that only about one-third of the healthy fly larvæ had transformed. This amounted to about 1.4 per cent of the total number of flies.

⁷ Op. cit.

Correcting the figures to correspond with what actually happened in the field and calculating in the same way as before, it is found that this extremely small percentage of flies transforming in this stubble field in the fall would amount to 68,600 flies per acre, with 60 per cent or 41,160 females. These females would lay enough eggs to develop into 9,466,800 flies per acre in young wheat sown in the fall of 1919. This is a much smaller number than had been anticipated, but it will be readily seen that even this is an enormous infestation. If the farmer sows about the same acreage from year to year and no flies are lost by migration, then the flies from an acre of stubbles would proceed to an acre of new wheat. It is calculated that 1,000,000 plants per acre is a good stand, and in that case this farmer would have over nine flies developing on every wheat plant. It will be readily seen from this that his chances of securing a wheat crop under the conditions named are practically zero. It is also evident that anything which helps to cut down this rate of reproduction is of enormous benefit. The principal checks to the multiplication of the Hessian fly are its parasitic enemies and unfavorable weather conditions, and if it were not for them it probably would be impossible inside of two years to grow wheat at all. This illustration, it is hoped, will also help to explain how an outbreak may seem to develop suddenly from a very low infestation of stubbles.

CONCLUSIONS.

The principal points made in this bulletin may be summarized as follows: /

1. The rate of multiplication of the Hessian fly is much higher than has been realized.

2. The rate of multiplication is quite different in the two principal broods of the Hessian fly, the spring brood laying on an average only about 230 eggs per female, whereas the fall brood lays about 285 eggs per female.

3. The capacity for reproduction also varies with a number of other factors, such as date of sowing, number of puparia per tiller, etc.

4. Because of these various influences, the actual rate of multiplication will be found to vary from year to year and even from field to field, and in years of light infestation the figures will prove too low.

5. The proportion of males to females varies in the two principal generations. In the spring generation about 60 per cent of the flies are females; in the fall generation the sexes are approximately equal in number.

6. By applying these figures, however unsatisfactory the basis may be, it is believed that entomologists will be better able to appreciate how a Hessian fly outbreak may develop very suddenly, and to predict in a more accurate manner the approach of a dangerous outbreak.

DIV. INSECT

UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 1016



Contribution from the Bureau of Entomology

L. O. HOWARD, Chief

Washington, D. C.

PROFESSIONAL PAPER

January 31, 1922

BIONOMICS OF THE CHINCH BUG.

By PHILIP LUGINBILL, *Entomological Assistant, Cereal and Forage Insect Investigations.*

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INTRODUCTION.

During several years past the biology of the chinch bug (*Blissus leucopterus* Say) has been studied in South Carolina with a view to the control of the insect in that region. It is a pest of considerable importance, especially in some of the northern counties of the State. Many planters in this region will plant no grain, giving as a reason that attempts to grow grain result in producing chinch bugs, and as a consequence they are unable to make a corn crop. Coincident with the conduct of field investigations, some time was devoted to a study of the insect in the laboratory at Columbia, and although this work is not complete, certain novel facts regarding the life history of the pest have been learned which make it advisable to publish immediately the information thus obtained. Wherever the chinch bug has been treated in the literature, it has always been represented as passing through five instars in its development. By means of the experiments conducted at Columbia, S. C., it has been shown that in this locality the insect has six instars, instead of five, exclusive of the egg stage, viz, five immature stages, the sixth being the adult stage. The figures of the stages of this insect given by C. V. Riley, which have been used over and over again in various bulletins and other works on this subject, therefore are incorrect, at least in so far as South Carolina is concerned. Specimens of the different stages were preserved at Columbia, and from these drawings have been made by

Miss E. H. Hart, to whom much credit is due. A dipterous parasite of the adult insect has also been reared for the first time, as described below.

SEASONAL HISTORY IN SOUTH CAROLINA.

NUMBER OF GENERATIONS.

There are two generations of the chinch bug annually in the South, the same as in the North. The adults begin to mate shortly after they emerge from hibernation quarters, this emergence occurring during the latter part of April, as mentioned elsewhere in this paper. A few pairs in copula, however, have been collected prior to this date. General copulation does not occur until after the spring migration, or after the adults have reached their feeding ground; it usually takes place during the first week in May, although the time varies somewhat. Eggs are deposited shortly after, and by the latter part of May nymphs appear. By the end of the first week in June the majority of the old adults are dead and by the middle of the same month new adults begin to appear, although not attaining their maximum abundance until some time in July. Part of June, July, and part of August are covered by the second generation, which may be called the summer generation. The adults from this generation appear in September and October, and some probably in early November, and go into hibernation for the winter. The two generations overlap to such an extent that during the summer months all stages of the insect may be found in the fields at once.

HIBERNATION.

In the South this insect passes the winter in the adult stage among old, dead cornstalks, especially under their leaf sheaths and in their husks. There is no doubt that many individuals also hibernate among dead grass, along terraces and borders of fields. They are not found in any great numbers in any one place during this season of the year, but are fairly well scattered, so much so that it is a difficult matter to find any quantity of them at any one time. The bugs apparently feed but little during winter but remain hidden until the warm spring sun arouses them to activity and they prepare for their spring migration.

DISSEMINATION.

This insect migrates from its winter quarters to grain fields principally by flight. The adults of the hibernating generation apparently consist exclusively of winged forms and are fully capable of spreading into fields of forage and grain. Thus far no short-winged individuals have been found among the spring migrants. The exact time when migration takes place in spring has not been definitely

determined, but apparently it is during the month of April. Migration is governed largely by seasonal conditions. The phenomenon of migration in this insect in spring on such an extended scale is a topic for general conversation among the planters in regions subject to infestation. The planters state that during migration the bugs fill the air like swarms of bees and are even known to enter dwellings at night. To a lesser extent the adults spread on foot to grain fields from their winter quarters, especially when such fields are not far removed from where the bugs have hibernated. It is not an uncommon practice in the South to sow grain, especially winter oats, on corn stubble land, and in such cases the adults find their food without having to search for it. There does not appear to be any definite summer migration. This may be due partly to the fact that a large number of the individuals of the summer generation are short-winged forms, unable to fly, and hence are compelled to seek fresh fields by crawling to them.

BEHAVIOR.

Adult chinch bugs often feign death when disturbed, especially when they happen to be lying on their backs. When it is least expected, however, they will right themselves quickly and scamper away to seek concealment under the nearest shelter, and are then difficult to capture. They are exceedingly quick on their feet, and when a vial, in which they are held captive, is opened, are often able to regain their freedom before the observer realizes what has happened. When adults are captured in the field they frequently escape by crawling through the little spaces between one's fingers and quickly drop to the ground. The nymphs of all stages are quite as active as the adults and often escape from captivity in a similar manner. Activity, of course, depends upon prevailing temperatures. Early in the morning the adults and nymphs are often quite sluggish and are easily taken, but by the middle of the day they become exceedingly active.

This insect is a sociable creature, both in its nymphal and adult stages, and when a number of individuals are placed in the same cage they will be found, later on, feeding in a little group. When disturbed they scamper in all directions, to reassemble when danger has passed. Upon removal of the lid from a tin ointment box used as an incubation cage the nymphs that had hatched were often found huddled closely together in a little group along the edge on the underside of the lid, these nymphs being very small when newly emerged.

MATING.

Mating takes place repeatedly among the individuals of this species, and may occur at intervals of from 5 to 8 days. The adults remain in copula for some time, occasionally for 12 hours or more,

and during this time are easily captured. During copulation the female alone remains active, traveling about frequently, and dragging the male helplessly after her. There is little doubt that there are both polyandry and polygamy among the adults of the chinch bug, since they mate an indefinite number of times.

LIFE HISTORY OF THE CHINCH BUG.

OVIPOSITION.

Under field conditions eggs are placed by the female near or on the plants upon which the insect feeds. Eggs may be found in the soil near the roots, at the base of the plants, but more often occur in the leaf sheath, which appears to be the preferred place.

In the laboratory bacteriological test tubes, of standard size, stoppered with absorbent cotton and supplied with parts of corn plants, were found to be the most successful type of egg cage. The corn plants used as hosts were about 6 inches high, with their foliage and the outer roots cut off before introduction into the cage. Sometimes parts of larger cornstalks were used when young corn was not available. In cages where young corn was supplied the eggs were laid on all parts of the plant, but most frequently were placed under the upper epidermal layer of the leaf sheath. This appears to be their favorite location, although many eggs were placed in the cotton stopper of the vial. Where parts of cornstalks were used, the eggs were often found pushed into the pith, on either end, to their entire depth, sometimes two and three together. In the leaf sheaths they are often found in quantities, side by side. In one instance 16 eggs were found placed in this manner in a neat, compact row. With a little care the whole row was lifted out without any of the eggs becoming detached. It was not often that eggs were placed loosely in the vials. It seems that the female desires to conceal her eggs from possible predacious enemies.

Eggs in cages were deposited during all hours of the day. It is possible that some may be deposited during the night, but this is doubtful. In the field it is quite likely that very few eggs are deposited during early morning hours, the temperature at that time of the day being lower and damp, which causes the adults to become numb and therefore sluggish.

NUMBER OF EGGS DEPOSITED BY A SINGLE INDIVIDUAL.

Considerable variation has been noted in the number of eggs deposited by an individual female of this species. Such variation undoubtedly is governed to some extent by seasonal weather conditions. There is no doubt, however, that some females are by nature more fecund than others.

Females and males, taken in copula in the field very early in spring, were placed in test tubes and counts made of the number of eggs laid. Data relating to four of these cages are given in Table I. The largest number of eggs deposited in any one of the four cages was 119, in cage 20-51. The smallest number, 51, was obtained in cage 20-53. The average number deposited by one female, based on the four individuals, is 85.25 eggs. Oviposition extended over a period of 56 egg-laying days in cage 20-50, and only 41 days in cage 20-51, although more eggs were deposited in the former cage than in the latter.

Although the individuals were collected from the field, there does not seem to be much doubt that the females had begun to oviposit before they were captured, since they were taken at the time of their migration and shortly afterwards, and at the time when they were copulating in great numbers.

TABLE 1.—Records of daily and total egg production of four individuals of *Blissus leucopterus*, Columbia, S. C., 1920.

Cage No. 20-50.		Cage No. 20-51.		Cage No. 20-53.		Cage No. 20-55.	
Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.	Date of oviposition.	Number of eggs.
May 11.....	1	May 8.....	1	May 9.....	.....	May 9.....	.....
May 12-26.....	.....	May 9-25.....	.....	May 10.....	12	May 10.....	6
May 27.....	2	May 26.....	6	May 11.....	.....	May 11.....	.....
May 28-31.....	.....	May 27-28.....	.....	May 12.....	3	May 12.....	.....
June 1.....	2	May 29.....	2	May 13.....	1	May 13.....	2
June 2.....	1	May 30-31.....	9	May 14.....	2	May 14-24.....	.....
June 3.....	2	June 1.....	2	May 15-20.....	.....	May 25.....	6
June 4.....	3	June 2.....	5	May 21.....	3	May 26.....	.....
June 5.....	1	June 3.....	10	May 22-24.....	10	May 27.....	3
June 6-7.....	3	June 4.....	4	May 25.....	4	May 28.....	6
June 8-9.....	2	June 5.....	5	May 26.....	2	May 29.....	10
June 10.....	4	June 6-7.....	14	May 27.....	6	May 30-31.....	6
June 11.....	6	June 8-9.....	10	May 28.....	3	June 1.....	4
June 12.....	.....	June 10.....	2	May 29.....	5	June 2.....	13
June 13-14.....	14	June 11.....	5			June 3.....	6
June 15.....	2	June 12.....	3			June 4.....	10
June 16.....	7	June 13-14.....	23			June 5—Female dead; dissected.	3
June 17-18.....	10	June 15.....	11				
June 19.....	3	June 16.....	5				
June 20-21.....	12	June 17-18.....	2				
June 22-23.....	7						
June 24.....	2						
June 25-26.....	3						
June 27-29.....	.....						
June 30.....	1						
July 1-6.....	7						
Total.....	95	Total.....	119	Total.....	51	Total.....	75

LENGTH OF THE EGG STAGE.

The length of the incubation period is governed primarily by prevailing temperature. During early spring it may be slightly more than a month and during midsummer a trifle more than a week. In the laboratory at Columbia, S. C., a record on the incubation period

of 664 eggs was obtained during the spring and summer of 1919 and 1920. These data are given in Table 2. The longest period obtained for the egg stage was 31 days. This egg hatched on June 8 from a lot of 103 deposited on May 8. The shortest egg period was 9 days, during July. There is a gradual decrease in the length of the egg stage from early May to July, and during August it again increases.

Not all of the eggs of one day's deposition hatch on the same day, although the reason for this is not definitely known. It may be that some eggs are not sufficiently supplied with moisture, or with the same amount that the others receive, and consequently develop more slowly. There may be a difference of nine days in the time of hatching in the same lot of eggs, as will be noted in Table 2 under entry of May 8. The greater number of this lot of 103 eggs, however, hatched within 3 days after hatching began. The first eggs in this lot hatched on May 31, the last on June 8. There is a greater range in the time of hatching in a single lot of eggs in the early spring months than in the summer months. In the latter period a lot of eggs laid on the same day generally hatch within at most 3 days after hatching has begun, and quite often all of them hatch on the same day.

The weighted average for the egg period of the 664 eggs recorded in Table 2 is $21.96+$ days.

The type of cage used for observation purposes on the incubation period consisted of a very small tin ointment box with a plaster of paris bottom. The porous qualities of this substance permitted introduction of just the right amount of moisture. No great difficulty was experienced with fungus, which often develops in closed boxes where moisture is present, especially when used continuously for as long a time as in these experiments. This type of egg cage has been found exceedingly satisfactory for making observations on the egg stages of various insects, especially those which lay their eggs in the soil or other damp places, and therefore have to be kept fairly moist if good results are to be obtained. It was devised in connection with investigations of the southern corn rootworm (*Diabrotica 12-punctata* Oliv.).

TABLE 2.—Length of incubation period of eggs of *Blissus leucopterus*, Columbia, S. C., 1919-20.

Eggs deposited.		Eggs hatched.		Length of egg stage.	Eggs deposited.		Eggs hatched.		Length of egg stage.
Date.	Number.	Date.	Number.		Date.	Number.	Date.	Number.	
				Days.					Days.
May 4.....	3	May 29.....	3	25	June 1.....		June 17.....	8	16
May 6.....	6	May 31.....	1	25			June 18.....	1	17
		June 1.....	3	26	June 2.....	33	June 17.....	14	15
		June 2.....	2	27			June 18.....	12	16
May 8.....	103	May 31.....	12	23			June 19.....	2	17
		June 1.....	43	24	June 3.....	32	June 20.....	2	18
		June 2.....	40	25			June 16.....	1	13
		June 3.....	2	26			June 17.....	3	14
		June 4.....	1	27			June 18.....	8	15
		June 5.....	2	28			June 19.....	16	16
		June 6.....	2	29			June 20.....	1	17
		June 7.....					June 21.....	1	18
		June 8.....	1	31			June 22.....	2	19
May 9.....	9	June 2.....	6	24	June 4.....	17	June 18.....	4	14
		June 3.....	3	25			June 19.....	7	15
May 10.....	37	June 2.....	19	23			June 20.....	5	16
		June 3.....	14	24			June 21.....		
		June 4.....	2	25	June 5.....	12	June 22.....	1	18
		June 6.....					June 19.....	1	14
		June 6.....	2	26			June 20.....		
May 11.....	21	June 2.....	3	22			June 21.....	10	16
		June 3.....	11	23			June 22.....		
		June 4.....	5	24	June 10.....	6	June 23.....	1	18
		June 5.....					June 22.....	1	12
May 12.....	48	June 6.....	2	26			June 23.....	4	13
		June 3.....	4	22			June 24.....	1	14
		June 4.....	28	23	June 11.....	10	June 23.....	2	12
		June 5.....	11	24			June 24.....	5	13
		June 6.....	5	25			June 25.....	3	14
May 13.....	39	June 3.....	1	21	June 12.....	9	June 24.....	3	12
		June 4.....	8	22			June 28.....	6	16
		June 5.....	12	23	June 15.....	11	June 28.....	2	13
		June 6.....	18	24			June 29.....	7	14
May 17.....	66	June 6.....	14	20			July 1.....	2	16
		June 7.....	39	21	June 19.....	3	July 3.....	3	14
		June 8.....	13	22	June 23.....	7	July 6.....	7	13
May 18.....	2	June 9.....	1	22	June 26.....	1	July 9.....	1	13
		June 10.....	1	23	June 27.....	46	July 10.....	44	13
May 19.....	12	June 7.....	12	19			July 12.....	2	15
May 21.....	3	June 12.....	3	22	June 28.....	5	July 11.....	2	13
May 22.....	2	June 12.....	2	21			July 12.....	3	14
May 25.....	58	June 14.....	18	20	July 1.....	1	July 12.....	1	11
		June 15.....	39	21	July 7.....	14	July 16.....	1	9
		June 16.....	1	22			July 17.....	2	10
May 26.....	22	June 14.....	6	19			July 18.....	11	11
		June 15.....	16	20	July 8.....	6	July 20.....	6	12
May 27.....	27	June 14.....	1	18	July 11.....	12	July 23.....	12	12
		June 15.....	23	19	July 12.....	14	July 25.....	13	13
		June 16.....	3	20			July 26.....	1	14
May 28.....	18	June 15.....	14	18	July 24.....	2	Aug. 4.....	2	11
		June 16.....	4	19	July 26.....	5	Aug. 8.....	5	13
May 29.....	23	June 15.....	1	17	July 27.....	2	Aug. 5.....	2	9
		June 16.....	22	18	Aug. 21.....	6	Sept. 5.....	6	15
June 1.....	11	June 16.....	2	15					

Total number of eggs, 664. Weighted average for the egg period, 21.96 + days.

FERTILITY OF THE EGGS.

Not all of the eggs laid by the chinch bug are fertile. Fertility may depend upon the number of times the female has mated or upon whether or not the female has recently mated. The fact that the female lays infertile eggs at times may explain the necessity for frequent copulation, for should she mate only once or the mating interval be too great, more of the eggs might be infertile. This, however, is somewhat conjectural and further observations on this point are necessary. In one instance 40 eggs out of a total of 503, or about 8 per cent, were infertile. In another case 5 eggs out of

a total of 56, or about 9 per cent, were infertile. In both instances males were with the females at all times.

NUMBER AND LENGTH OF INSTARS AND TOTAL LENGTH OF THE IMMATURE PERIOD.

According to experiments conducted at the laboratory at Columbia, S. C., in 1919, and again in 1920, the nymphs of this species molt five times during their development from egg to adult, the same number of times as do the nymphs of the squash bug (*Anasa tristis* De G.) and the harlequin cabbage bug (*Murgantia histrionica* Hahn). These species, although belonging to different families from the chinch bug, differ from this insect mainly in taxonomic characters rather than in their bionomics. There are indications that occasionally a nymph may molt only four times, as originally supposed, and very rarely six times. This, however, is the exception rather than the rule, and such variation is known to occur among larvæ of various species of lepidopterous insects.

TABLE 3.—Number and length of instars and total length of immature period of *Blissus leucopterus*, Columbia, S. C., 1919–20.

Cage No.	Nymph emerged.	Date of first molt.	Length of first instar.	Date of second molt.	Length of second instar.
			Days.		Days.
¹ 19-450	July 11.....	July 27.....	16	Aug. 2.....	6
19-454	July 11.....	July 27.....	16	July 31.....	4
19-459	July 16.....	July 27.....	11	July 31.....	4
19-462	July 9.....	July 18.....	9	July 24.....	6
19-463	July 10.....	July 19.....	9	July 26.....	7
19-466	July 10.....	July 27.....	17	July 31.....	4
19-468	July 10.....	July 20.....	10	July 27.....	7
19-473	July 16.....	July 27.....	11	Aug. 2.....	6
19-476	July 17.....	July 30.....	13	Aug. 4.....	5
19-478	July 17.....	July 27.....	10	July 31.....	4
19-528	July 26.....	Aug. 1.....	6	Aug. 10.....	9
² 20-700	June 11.....	June 29.....	18	July 5.....	6
20-736	June 15.....	June 29.....	14	July 5.....	6
20-747	June 15.....	June 29.....	14	July 5.....	6
20-748	June 15.....	June 29.....	14	July 5.....	6
20-751	June 12.....	June 28.....	16	July 5.....	7
Average.....			12.75		5.75

Cage No.	Nymph emerged.	Date of third molt.	Length of third instar.	Date of fourth molt.	Length of fourth instar.	Date of fifth molt (adult).	Length of fifth instar.	Total length of immature period.
			Days.		Days.		Days.	Days.
¹ 19-450	July 11....	Aug. 10....	8	Sept. 5....	26	Oct. 4.....	29	85
19-454	July 11....	Aug. 9....	9	Aug. 15....	6	Sept. 5....	21	56
19-459	July 16....	Aug. 9....	9	Aug. 19....	6	Sept. 17....	29	63
19-462	July 9....	Aug. 2....	9	Aug. 13....	11	Sept. 8....	26	61
19-463	July 10....	Aug. 5....	10	Aug. 15....	10	Aug. 31....	16	52
19-466	July 10....	Aug. 8....	8	Aug. 21....	13	Sept. 20....	30	72
19-468	July 10....	Aug. 4....	8	Aug. 21....	10	Oct. 9.....	49	91
19-473	July 16....	Aug. 9....	7	Aug. 19....	17	Sept. 5....	17	51
19-476	July 17....	Aug. 7....	3	Aug. 29....	22	Oct. 4.....	36	78
19-478	July 17....	Aug. 7....	7	Aug. 15....	8	Sept. 16....	32	61
19-528	July 26....	Sept. 10....	31	Oct. 1.....	21	Oct. 28....	27	94
² 20-700	June 11....	July 12....	7	July 20....	8	Aug. 3.....	14	53
20-736	June 15....	July 17....	12	Aug. 8.....	22	Aug. 29....	21	75
20-747	June 15....	July 10....	5	July 26....	16	Aug. 5.....	10	51
20-748	June 15....	July 9.....	4	July 19....	10	Aug. 11....	23	57
20-751	June 12....	July 12....	7	July 29....	17	Aug. 14....	16	63
Average.....			9		14.12+		24.56+	66.43

¹ 19 refers to the year 1919.

² 20 refers to the year 1920.

The data obtained in connection with the experiments on the number and length of instars of 16 individuals have been summarized in Table 3. In another series of approximately equal number, under observation for about the same period as were those of 1919 given in Table 3, four molts only were observed and the nymphs were then in their penultimate stage. The length of the period of the first instar, according to Table 3, varies from a minimum of 6 to a maximum of 18 days, the second varies from 4 to 9 days, the third from 3 to 31 days, the fourth from 6 to 26 days, and the fifth from 10 to 26 days. Taking the averages obtained in the series, the period of the second instar is the shortest, the third somewhat longer than the second, the fourth slightly longer than the first, and the fifth much the longest of all. The greatest number of days required for any one of the individuals in the series to reach maturity was 94, and the smallest number 51. The general average for the total length of the immature period in the series is 66.43 days.

It is not unlikely that the length of the instars and the length of the immature period were somewhat extended, because the nymphs were kept under somewhat unnatural conditions. In this study of number and length of instars in this species small shell vials (30 mm. in length) were found the most convenient and satisfactory. These were stoppered with absorbent cotton and the cotton was moistened as often as necessary when observations were made. Small bits of cornstalks were supplied as food for the nymphs. It was necessary to be very cautious to prevent an oversupply of water from gathering on the sides of the vials. When droplets gather the nymphs, in crawling along the sides, are overcome by the water and become helpless, and if not assisted to a drier place and the vial dried out will die in a short time.

ECDYSIS.

A short time before the nymph casts its skin it becomes much swollen, especially in the abdominal region. The abdomen is then much wider than the thorax, particularly in the region of the fourth and fifth segments. Before this it is about the same width as the thorax or a little wider. The period during which the nymph has this swollen appearance will be called the molting period, and preparations are then being made by the nymph to cast off its outer cuticular layer. This period corresponds precisely to that in lepidopterous larvæ known as the molting period, during which the larvæ become sluggish, feed little or none, and prepare to shed their outer coat.

Specimens used for drawings of the various nymphal instars by C. V. Riley apparently were all in the molting stage, as the figures representing the instars show the nymphs much swollen. These drawings, therefore, are incorrect, even if the insect should have

had only five stages instead of six. The specimens used for the figures in this paper all had fed for some time after casting their last molt. In most cases the specimens were preserved for three, but in some cases for only two days after molting and during this period the individual was permitted to feed. Illustrations of specimens which have just molted and have not fed, or specimens about to molt, are likely to be misleading, as they are not normal representatives of the stage desired. Very often the color pattern of a specimen fades considerably just before molting, and if drawings are made at that time the color pattern for that instar will be wrongly recorded.

The nymphs of the chinch bug during the molting period feed very little, and their color pattern fades toward the close of the period. This fading is due to the loosening of the transparent cuticular layer, which is about to be cast. The darker color pattern of the succeeding instar can often be seen through the thin layer.

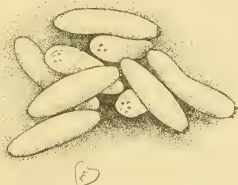


FIG. 1.—The chinch bug (*Blissus leucopterus*): Cluster of eggs, showing tubercles at the truncated or blunt ends. Greatly enlarged.

One nymph was caught in the act of casting its skin. When first observed it had already freed part of the abdomen and thorax. It then drew its legs out one at a time and by a jerky motion of the abdomen freed itself entirely from the old skin. The

nymph utilized its last pair of legs to push off the skin from the tip of the abdomen.

DESCRIPTION OF THE EGG AND NYMPHAL STAGES.

A description of the egg (fig. 1) and nymphal stages is given below. It does not seem necessary to describe the adult or the sixth instar (fig. 2, *f*), but a brief discussion of the sexual differences in the adult stage is included. It seems important that the sexual differences be known in order to facilitate biological work on this insect.

EGG.

The egg is elongate ovate, slightly reniform in shape, rounded at one end and truncate at the other. The truncate end is supplied with from three to five, usually four, tubercles 0.1 millimeter in length; opaque white in color when just deposited, turning amber in a few days and deep red several days before hatching. Just prior to hatching the embryo shows through the chorion which is smooth, shiny, and somewhat iridescent.

Length, 0.858 mm.; width, 0.308 mm.

FIRST INSTAR.

FIG. 2, *a*.

Head brown; width, 0.235 mm.; eyes dark red; proboscis pale except tip which is dusky; antennal segments dusky, segment 4 of antenna about twice the length of any one of the others, points of articulation pale.

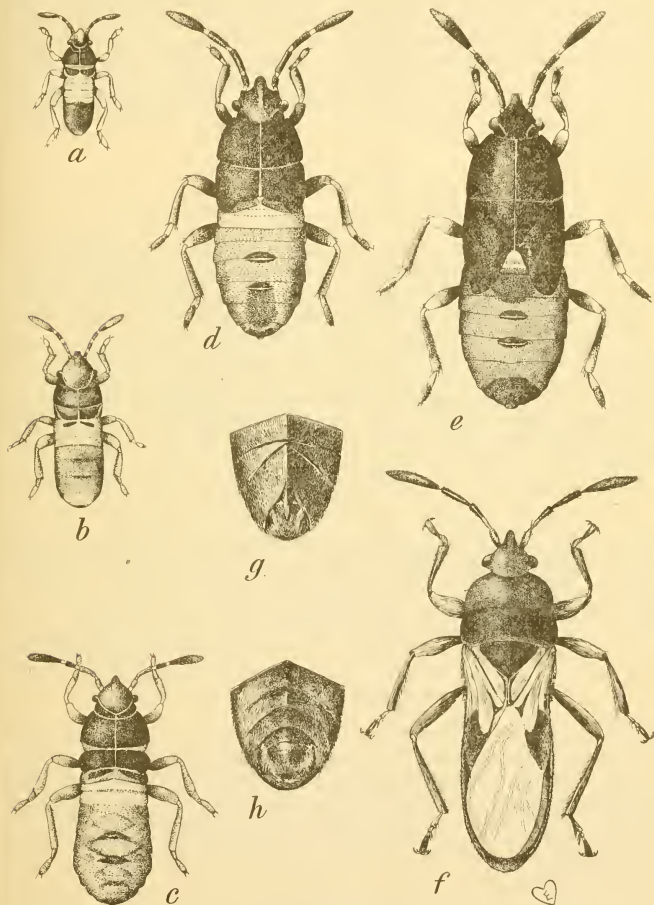


FIG. 2.—The chinch bug: *a*, Nymph, first instar; *b*, nymph, second instar; *c*, nymph, third instar; *d*, nymph, fourth instar; *e*, nymph, fifth instar; *f*, adult of long-winged form; *g*, tip of abdomen of adult female, ventral view; *h*, tip of abdomen of adult male, ventral view. Greatly enlarged.

Thorax 0.234 mm. in width; legs pale, the tarsi distinctly two-jointed; pronotum brown and coriaceous over the whole surface, 0.104 mm. in length; mesonotum pale except the small coriaceous patch on either side of the meson,

which is brown, 0.062 mm. in length; metanotum pale except a narrow dark line on either side of the meson, 0.047 mm. in length. The coriaceous area on the thorax is broken on the meson and causes it to appear as though crossed by a pale line.

Abdomen about the width of the thorax, though sometimes somewhat wider, the widest part being in the region of the fourth segment. Segments 1 and 2 pale yellowish white, this color sometimes invading part of the third segment; remaining segments light red, darkening somewhat in older individuals. There is a minute, dark spot on the meson near the caudal margin of the fourth segment and a similar one on the caudal margin on the meson of the fifth segment. In some specimens these spots are absent during the first instar. Tip of abdomen black.

Length, 0.889 mm.

SECOND INSTAR.

FIG. 2, b.

Head brown; width, 0.314 mm.; eyes, antennæ, and beak as in first instar.

Thorax, 0.513 mm. in width; legs pale as in previous instar; pronotum resembling previous instar; mesonotum coriaceous over almost its entire surface; metanotum with two brown coriaceous patches, one on either side of the meson, resembling large exclamation points; otherwise the segment is pale.

Abdomen, 0.502 mm. in width, widest in region of fourth segment. Segments 1 and 2 pale; remaining segments darker red than in preceding instar. The dark spots on the fourth and fifth segments are somewhat larger than in the preceding instar, but have not taken on any definite shape. Tip of the abdomen black, as also the area around the anal opening.

Length, 1.287 mm.

THIRD INSTAR.

FIG. 2, c.

Head dark brown; width, 0.399 mm.; eyes very dark red; proboscis amber except at tip, which is almost black; segments 3 and 4 of antennæ black, 1 and 2 amber, segment 4 twice as long as 2 and 3 and over three times as long as 1; points of articulation pale, somewhat translucent.

Thorax, 0.518 mm. in width; legs amber, somewhat dusky on the femora; pronotum, mesonotum, and metanotum dark brown and coriaceous over the whole surface; wing pads discernible on the caudal border of the mesonotum near the outer edges, in the form of a slight extension or outgrowth of the coriaceous covering in this region.

Abdomen, 0.596 mm. in width, widest in region of fourth segment. Segments 1 and 2 pale whitish, remaining segments a dull red, with mottlings of a darker color here and there. The two spots on the abdomen assuming a definite shape somewhat resembling a flaxseed in outline, one spot on the caudal margin on the meson of the fourth segment and the other on the meson of the fifth segment extending partly over the suture of the fifth and six segments. Tip of abdomen black.

Length, 1.648 mm.

FOURTH INSTAR.

FIG. 2, d.

Head, eyes, antennæ, and proboscis the same color as in the preceding instar; width of head, 0.465 mm.

Thorax, 0.654 mm. in width; legs same in color as in preceding instar; mesonotum very narrow, only about half as long as the pronotum and only a

small area of this segment visible on the meson and appearing whitish. Wing pads now conspicuous and extending about half way across the first abdominal segment.

Abdomen, 0.696 mm. in width. Segments 1 and 2 pale whitish as before, remaining segments dark red with streaks of black, giving it a blackish appearance. The black spot on the meson of the fourth abdominal segment very conspicuous. The other spot has moved farther caudad and is now found just below the suture separating the fifth from the sixth abdominal segment, or on the meson of the cephalic border of the sixth segment. Tip of abdomen black, including a small area around the anal opening.

Length, 2.114 mm.

FIFTH INSTAR.

FIG. 2, *e*.

Head black; width, 0.591 mm.; polished; eyes very dark red; proboscis amber, except tip which is black; antennal segment 1 amber, 0.157 mm. long, segment 2 amber, 0.314 mm. long, segment 3 black, 0.282 mm. long, segment 4 black, 0.518 mm. long; points of articulation pale.

Thorax, 0.937 mm. in width; legs dark; femora almost black; tibiae light amber except tibia of third pair of legs, which is darker; tarsi dark amber; joints lighter. Pronotum, mesonotum, and metanotum black, polished. Wing pads now extending to the caudal margin of the third abdominal segment.

Abdomen, 0.957 mm. in width; widest in region of fourth segment as before. First and second segments not visible except for a small portion on the meson, remainder of these segments covered by the wing pads, whitish. Remaining segments very dark red, almost black, with a number of dark areas and blotches almost black in color, tinged with blue, iridescent. Under the unaided eye the abdomen appears black. There is a velvety area on the meson of the third segment, sometimes extending partly over the fourth segment as well. The black patch which was on meson of abdominal segment 4 in preceding stages is now on the suture separating segments 4 and 5. The other, which was on the meson of the fifth segment in the first, second, and third instars, and on the sixth abdominal in the fourth, is now on the suture separating the fifth and sixth segments. These patches are very conspicuous. The tip of the abdomen is black as well as a considerable area surrounding it; in fact, most of the abdomen caudad of the seventh segment is black.

Length, 2.967 mm.

SEXUAL DIFFERENCES AMONG ADULTS.

The male chinch bug generally is not so large and robust as the female. There are other more conspicuous characters, however, that distinguish the sexes. If the lower, ventral part of the abdomen of either sex is closely examined, it will be noted that the abdomen of the male is rounded (fig. 2, *h*), while that of the female has a distinct ridge on the ventro-meson, giving the abdomen an outline in the form of an inverted V (fig. 2, *g*). Furthermore, the tip of the abdomen in the male is rounded, and surrounding the genital opening, especially along the upper border and the sides, the area is well supplied with moderately long hairs. In the female the last segment on the ventro-meson is adjusted to shield the ovipositor and its mechanism.

A PARASITE OF THE ADULT.

From time to time collections of adults and nymphs of the chinch bug have been made in fields about Rock Hill, S. C., and brought to the laboratory at Columbia, S. C., for breeding work. No special attention was given to the possibility of rearing a parasite from the adult. A large number of adults, however, comprising a portion of the material mentioned, yielded a tachinid parasite which emerged from a male individual. The host specimen was collected by Mr. Samuel Blum on May 7. The puparium was formed on May 8 and the adult fly issued on May 20. The puparium was at first a golden color, later turning a dark red. This parasite has been determined by Mr. W. R. Walton as *Phoranthia occidentis* Walk., and the determination has been verified by Dr. J. M. Aldrich of the United States National Museum.

Very little is known concerning this parasite except that it has been reared from two other hosts, both belonging to the order Hemiptera. Mr. F. B. Milliken reared an adult of this species in 1913 from an adult of the false chinch bug (*Nysius angustatus* Uhl.) and Mr. M. D. Leonard reared it from the capsid bug *Miris dolabratus* L. As far as the writer has been able to learn, this is the first record of the rearing of a dipterous parasite from the chinch bug, although a hymenopterous parasite (*Eumicrosoma benefica* Gahan) was reared by Mr. J. W. McColloch of the Kansas Agricultural Experiment Station several years ago from eggs of this species.

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L. O. HOWARD, Chief

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PROFESSIONAL PAPER

March 13, 1922

APANTELES MELANOSCELUS, AN IMPORTED PARASITE
OF THE GIPSY MOTH.

By S. S. CROSSMAN,¹ Entomological Assistant, Gipsy Moth and Brown-Tail Moth
Investigations.

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INTRODUCTION.

From the year 1905 to December 1, 1911, the State of Massachusetts and the Bureau of Entomology, United States Department of Agriculture, shared the expenses involved in carrying on an investigation of the natural insect enemies of the gipsy moth (*Porthetria dispar* L.) and the brown-tail moth (*Euproctis chrysorrhoea* L.) in Europe and of the introduction of parasites of these insects from

¹ The writer wishes to acknowledge the efforts of all those who have been connected with the Gipsy Moth Laboratory during the period covered by this report, who have assisted at various times in gathering and recording some of the data from which this bulletin has been prepared. H. A. Preston and C. E. Hood took most of the photographs and W. N. Dovener made the drawing of the adult *Apanteles*. He wishes especially at this time to express his appreciation and thanks to A. F. Burgess, who has general direction of the work, for his help and suggestions.

their native homes to New England. A comprehensive report² of this work from its beginnings through 1910 has been published in Bulletin 91 of the Bureau of Entomology.

Among the imported parasites which are now established is *Apanteles melanoscelus* Ratz., a double-brooded parasite of the gipsy moth. The following report has been prepared in two parts: Part I contains the description of the species and its life history, and Part II takes up its introduction and establishment.

PART I.—DESCRIPTION AND LIFE HISTORY.

HISTORY.

The insect was described by Ratzeburg³ in 1844 very briefly as follows (translation):

Microgaster melanoscelus is so similar to *solitarius* that, since it also has the same mode of life, one might regard it as merely a variety of that species; but it is distinguished not only by the very black femora. . . but also by the third abdominal segment being scarcely rugose, only coarsely punctate at base. Pits at the base of the scutellum very narrow. The one male which I possess is only one line long.

In 1852 Ratzeburg⁴ again mentions this species and gives a record of its being reared from *Porthetria dispar* L. and *Stilpnotia salicis* L.

Reinhard⁵ writes in 1880 as follows:

The specimens called by Ratzeburg (Ich. der Forstinsect. III) *Apanteles melanoscelus*, bred from *Liparis salicis*, are beyond all doubt this species.

Reinhard is here speaking of *A. solitarius* and believes the two to be synonymous. In the same article he places Ratzeburg's type of *A. melanoscelus* in *A. difficilis* (Nees) Reinh. This is undoubtedly incorrect, as the biology of the two parasites is very different.

Marshall⁶ writes in part as follows of *A. difficilis*:

Common. The cocoons are flesh-colored or buff . . . ; a few, by some accident, are more yellow. The maggots, on leaving the body of their victim, make separate naked cases, without clustering together. From 1 to 20 issue from a single caterpillar, according to its size.

Dalla Torre⁷ in 1898 also considered *melanoscelus* synonymous with *A. difficilis* (Nees) Reinh.

² HOWARD, L. O., and FISKE, W. F. THE IMPORTATION INTO THE UNITED STATES OF THE PARASITES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH. U. S. Dept. Agr. Bur. Ent. Bul. 91. 344 p., 74 figs., 27 pl. (1 col.). 1911.

³ RATZEBURG, JULIUS THEODOR CHRISTIAN. DIE ICHNEUMONEN DER FORSTINSECTEN, v. 1, p. 74, no. 21. 1844.

⁴ RATZEBURG, JULIUS THEODOR CHRISTIAN. DIE ICHNEUMONEN DER FORSTINSECTEN, v. 3, p. 56, no. 51. 1852.

⁵ REINHARD, H. BEITRÄGE ZUR KENNNTNIS EINIGER BRACONIDEN-GATTUNGEN. In Deutsche Ent. Zeitschr., jhrg. 24, heft 2, p. 352-370. 1880.

⁶ MARSHALL, T. A. MONOGRAPH OF BRITISH BRACONIDAE, Pt. 1. In Trans. Ent. Soc. London, 1885, p. 163.

⁷ DALLA TORRE, C. G. DE. CATALOGUS HYMENOPTERORUM, v. 4, BRACONIDAE, p. 168. 1898.

DISTRIBUTION IN EUROPE.

Apanteles melanoscelus is probably present over most of Europe. Specimens have been received at the Gipsy Moth Laboratory from Vienna, Austria; Sicily, Italy; Bendery, Russia; and from Saxony, Brandenburg, Pomerania, and Rhenish Prussia, Germany.

DESCRIPTION OF SPECIES.

It is evident that *solitarius* and *melanoscelus* are closely related, and in time it may be shown that they are the same. If such should prove to be the case, the name *melanoscelus* would have to go, as *solitarius* has the priority. For the present they are to be considered as distinct species, and as Ratzeburg's⁸ description of *A. melanoscelus* is very meager, the following new description has been prepared.⁹

FEMALE.

Length 3 mm. Face feebly shagreened and strongly shiny, with a weak median welt below insertion of antennæ; vertex, temples, and cheeks shagreened, pilose, shiny; mesoscutum shallowly, sometimes indistinctly punctate and shiny; scutellum with the disk very slightly convex, smooth, and polished; mesopleuræ smooth and highly polished, with only a few punctures anteriorly and below, and a conspicuous weakly crenulate depression posteriorly; propodeum rugose except at base, strongly shiny, and with a prominent median longitudinal carina; forewing with stigma large and with the radius very distinctly longer than the transverse cubitus; posterior coxæ large, smooth, and shiny, with a conspicuous flattened area on outer edge at base; spurs of posterior tibiæ equal in length and about half as long as the metatarsus. Abdomen stout; entirely shiny; first tergite broader at apex than at base, rugose punctate; second broad, rectangular, more or less roughened, without distinct lateral membranous margins; third tergite with the rugosity usually confined to the extreme base; remainder of abdomen polished; ovipositor hardly exerted; hypopygium not extending beyond apex of last dorsal segment. Black; antennæ entirely black; tegulæ black; wings hyaline, the stigma dark brown; all coxæ and trochanters black, except sometimes apex of the latter; base of fore femora usually, basal half of middle femora, and most of the posterior femora black or blackish; apical fourth of hind tibiæ and the hind tarsi dusky; sides and venter of the abdomen black. (Pl. I, A.)

MALE.

Essentially as in the female. Differs only in the longer antennæ, in the usually darker legs, and in the basal abdominal tergites being less roughened.

The species is exceedingly close to *A. solitarius* Ratzeburg, but apparently the differences are sufficiently well marked and sufficiently constant to justify holding the two forms distinct. In *A. solitarius* the antennæ are brownish testaceous toward base, the legs, with the exception of the coxæ and the basal trochanters, are practically en-

⁸ RATZEBURG, JULIUS THEODOR CHRISTIAN. OP. CIT. 1844.

⁹ The description and translations of references Nos. 3 and 5 were made by Mr. C. F. W. Muesbeck.

tirely stramineous, and the three basal abdominal tergites are more coarsely rugose, the roughening on the third tergite extending well toward the posterior margin medially; the narrow lateral membranous margins on the apical fourth of the first abdominal tergite are testaceous in *A. solitarius*, while they are piceous black in *A. melanoscelus*.

METHODS USED IN BIOLOGICAL WORK.

As this species hibernates as a maggot within its cocoon, it is a simple matter to gather material during the fall and winter for study in the spring. The cocoons were kept in the laboratory yard during the winter, in cylindrical cages 3 by 8 inches, made of very fine copper netting. Occasionally during the winter a few cocoons were dissected to ascertain the condition of the maggots and to note any changes which might have taken place. As spring approached, the

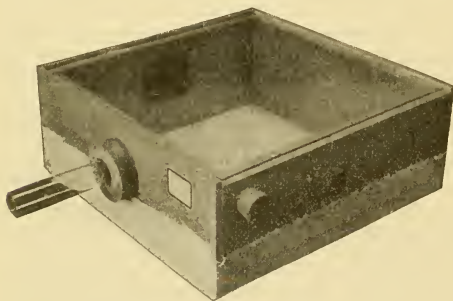


FIG. 1.—Tray with glass top used in life-history experiments with *Apanteles melanoscelus*. (After Culver.)

cocoons were isolated, being placed in small gelatin capsules, or small glass vials $1\frac{1}{2}$ inches by $\frac{1}{2}$ inch. It is necessary to isolate each of the cocoons at this time of the year for two reasons: First, so that one may know the exact age of the adults with which he is

working and keep the males and females separate; second, to prevent any secondary parasites which may issue from the cocoons during the spring from ruining the rest of the *Apanteles* material.

As soon as the *Apanteles* issued they were removed from their containers and placed in glass tubes or glass-covered trays (fig. 1), where they were fed a mixture of equal parts of water and honey. A convenient method of feeding is to dampen a small piece of clean sponge with the food and place it in the tube or tray containing the *Apan-tele*s. The sponge should be washed out every day or so and dampened again with a fresh mixture of honey and water.

Parasite-free gipsy-moth larvæ were obtained by rearing them from eggs, and a supply was kept in trays protected from parasites ready for use at all times.

Two sizes of glass tubes were found convenient, a small one 4 inches by 1 inch for isolated individuals, and a larger size, 8 by 2

inches, for confining several. As the *Apanteles* are usually active and soon exhaust themselves if allowed to remain in the light, the tubes or cages containing them were kept dark when not in use.

Records of oviposition were obtained in the following manner: A glass tube containing a single female was brought into the light and a parasite-free gipsy-moth larva was introduced on the point of a small camel's-hair brush. As soon as the parasite oviposited in the caterpillar, the larva was removed to a can for rearing. This procedure was continued as long as a female would oviposit readily. As soon as she began to show a lack of interest in the gipsy-moth larvæ, she was returned to the dark to rest and a fresh female given an opportunity to oviposit.

After the first female had rested for an hour or two she was again brought into the light and presented with gipsy-moth larvæ as before. This process was continued with several females throughout their life.

The parasitized larvæ were kept isolated in cylindrical cans, which measured $2\frac{1}{2}$ by 2 inches, there fed, and kept for future study. The structure and length of the various larval instars were determined by daily dissections of these parasitized caterpillars.

LIFE HISTORY.

Apanteles melanoscelus hibernates as a third-stage maggot within its tough sulphur-yellow cocoon. Under field conditions the adults emerge from their cocoons over a period of about three weeks. Emergence is at its height when the gipsy-moth egg hatching is at its maximum, usually during the second week in May. The period of emergence of adults from cocoons kept at the laboratory where all of the cocoons are held under the same conditions is five or six days. The majority of the males emerge during the first four days; the females, beginning to emerge on the second day, continue emerging for four or five days, the bulk of emergence being on the third day after the first appearance of either sex. The adult escapes through a circular hole which it cuts at the anterior end of the cocoon.

Females of *A. melanoscelus* are ready for mating or for oviposition within two or three hours after issuing. They oviposit just as freely whether they have been fertilized or not, and, as is the case with many parasitic Hymenoptera, they often reproduce parthenogenetically.

This species does not copulate readily when enclosed in glass vials or small cages, but was often observed in coition in the large breeding chamber (Pl. V, C). The male approaches the female in the usual state of excitement with its antennæ and wings constantly vibrating. The act of copulation is a matter of a few seconds.

OVIPOSITION.

The act of oviposition takes about one second. The female may alight upon a gipsy-moth larva from flight or walk up to one. In either case the ovipositor is inserted and withdrawn very quickly and practically always an individual egg is deposited. Many larvæ have been dissected after apparent oviposition had been observed and in no case has more than one egg been found from a single oviposition and only rarely have dissections been made which failed to show the presence of an egg. Often the larva attacked thrashes about so violently that it and the parasite fall, but rarely does the parasite fail in its object. After ovipositing in a larva the female usually proceeds to another victim, but occasionally will oviposit a second time before leaving the caterpillar. She apparently does not examine a prospective host but attacks it whether it has previously been parasitized or not. This practice of occasionally placing an egg in a parasitized caterpillar is unfortunate as only very exceptionally will more than one maggot develop within a single host. The parasite favors the posterior half of the caterpillar for oviposition, but will oviposit in any segment of the body.

The females of *A. melanoscelus* which issue from hibernating cocoons prefer to parasitize the first and second stage gipsy-moth larvæ but will oviposit successfully in third-stage larvæ if they are present. When the next or summer generation of adults appear, most of the gipsy-moth larvæ are in the third stage. This is the stage most heavily attacked by this generation, although many fourth-stage caterpillars are successfully parasitized. *Apanteles* females of this generation often attempt oviposition in fifth and sixth stage larvæ but are not so successful, for they are hindered by the long hairs of large larvæ.

There was considerable variation in the number of ovipositions different individuals would make. Between 200 and 300 ovipositions per female were often obtained in these experiments. The greatest number of ovipositions secured by a single female of *A. melanoscelus* was 535. She actually had gipsy-moth larvæ before her for 510 minutes, making these ovipositions a little faster than one a minute.¹⁰ The parasite was allowed several oviposition periods each day and she would parasitize the gipsy-moth larvæ as fast as they were introduced for from 30 to 60 minutes. The first day the periods of oviposition were a little longer than during the following days. This female issued May 23 from its hibernating cocoon, but was not given an opportunity to oviposit until May 27, when

¹⁰ This is about as fast as larvæ can be introduced and withdrawn by the process used. Under more natural conditions, as found in the large breeding chamber, the females were often observed to oviposit 6 or 7 times a minute.

the first gipsy-moth larva was introduced. She worked actively every time she was allowed to do so each day to and including June 2. On the morning of June 3 she was found dead in the tube. A dissection showed that her ovaries still contained about 150 mature eggs and about 200 eggs in different stages of development.

From this and other records, together with notes made from dissections of mature females of *A. melanoscelus*, it seems safe to assume that under natural conditions each female is capable of depositing in the vicinity of 1,000 eggs.

EGG.

The egg at time of deposition averages 0.55 mm. in length and 0.1 mm. in width. It (Pl. I, B) is deposited singly in the body cavity just beneath the skin of the host. It is transparent, with the cephalic end rounded, the caudal end, which is slightly narrowed, bearing a short stock. The chorion appears to be entirely without ornamentation. Development within the egg is rapid and the embryo begins to show form after 15 to 20 hours (Pl. I, C). By this time the egg has widened a little and is slightly shorter than when first deposited. Many eggs have hatched 48 hours after deposition. Just before hatching, the fully developed embryo is plainly seen, often in the position illustrated in Plate I, D. At this time the egg measures 0.7 mm. in length and is greatly swollen around the area which incloses the head. On one occasion an egg, which was ready to hatch, burst while under observation and the larva floated out as illustrated in Plate I, E, after which the eggshell shriveled up considerably.

The length of the egg stage is from 48 to 72 hours, depending on the temperature. If the weather is warm, the majority of the eggs hatch in about two days.

LARVA.

FIRST-STAGE LARVA.

The following measurements are the average for newly-hatched larvæ: Total length, 0.7 mm.; width of head, 0.2 mm.; width of body, 0.1 mm.; length of caudal horn, 0.1 mm.

The freshly-hatched larva (Pl. I, F) is found free in the body cavity. Directly after hatching it may be found in almost any part of the cavity, depending on the point of deposition of the egg. After a few hours it works its way to the dorsal part of the posterior third of the host and usually remains in that area until about ready to issue as a third-stage maggot.

The larva is transparent and extremely delicate, with a large head which is twice the width of the body. The head is composed of a single segment. The labium, labrum, and maxillæ are present. The

sickle-shaped mandibles (Pl. I, J), which are well fitted for tearing, are plainly seen, being in motion much of the time, as the maggot feeds on the lymph and fat bodies of its host. They are 0.08 mm. long, are chitinized throughout, but more heavily so at the tips, and form a good character for distinguishing this stage from the following ones. The body is made up of ten segments at this period, but later has eleven after the tenth segment divides. On the dorsum the maggot has a systematic arrangement of short, rather stiff, backward pointing spines. The spines are located as follows: Two each on the second and third segments, four on the fourth segment, six each on the fifth to ninth segments inclusive, and eight on the tenth segment. It seems likely that these spines assist the maggot in working its way to the caudal end of the host.

The anal vesicle, which is common to the microgasterine larvæ, is prominent and the caudal horn is seen just beneath the evaginated anal vesicle.

As the larva matures, the heart, nervous system, and silk glands can be distinguished, but no evidence of the tracheal system is apparent.

When ready to molt the larva has increased in length to nearly 2 mm. and the body has widened in proportion, except the head, which remains about the same width throughout the stage.

The larva remains in this stage from two to three days in the spring generation and from six to eight days in the summer generation.

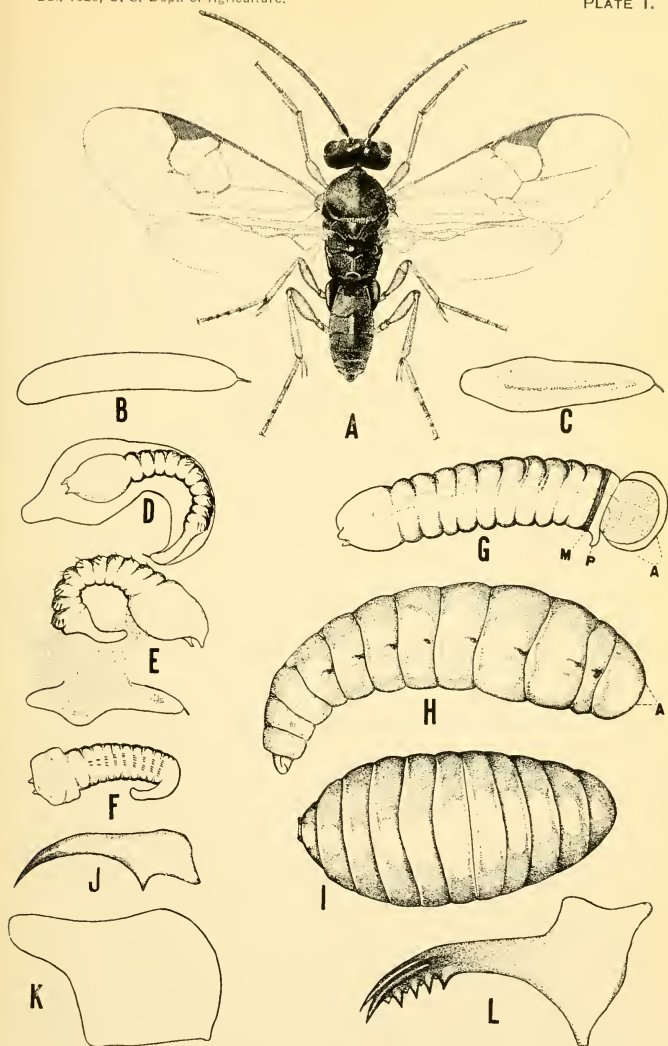
SECOND-STAGE LARVA.

In molting the head skin of the first-stage maggot is split off and is occasionally found in the body cavity of the host, closely associated with the cephalic region of the second-stage larva. The remainder of the molt skin is worked back to the last body segment (Pl. I, G at M).

The second-stage maggot is usually found dorsally in the caudal end of the host in the body cavity, its head toward the posterior end of the caterpillar and its body resting longitudinally. When first molted it measures about 2.75 mm. in length and 0.55 mm. in width, the head and body being approximately the same width.

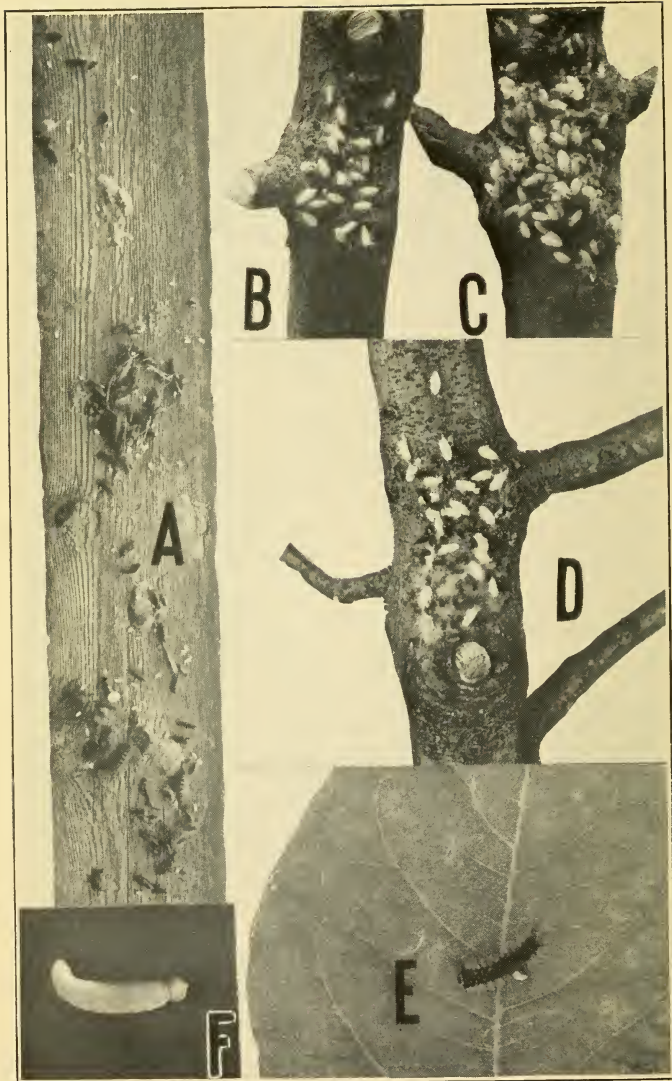
In contrast to the first-stage maggot the body is entirely destitute of spines and the mouthparts are poorly developed. The mandibles (Pl. I, K) are not fitted for tearing or biting, but are soft, fleshy forms without chitin and are very difficult to locate.

The anal vesicle is still present and is more prominent than in the previous stage (Pl. I, G at A). The caudal horn is present but has not grown with the developing maggot and appears very small in comparison with the size of the larva (Pl. I, G at P).



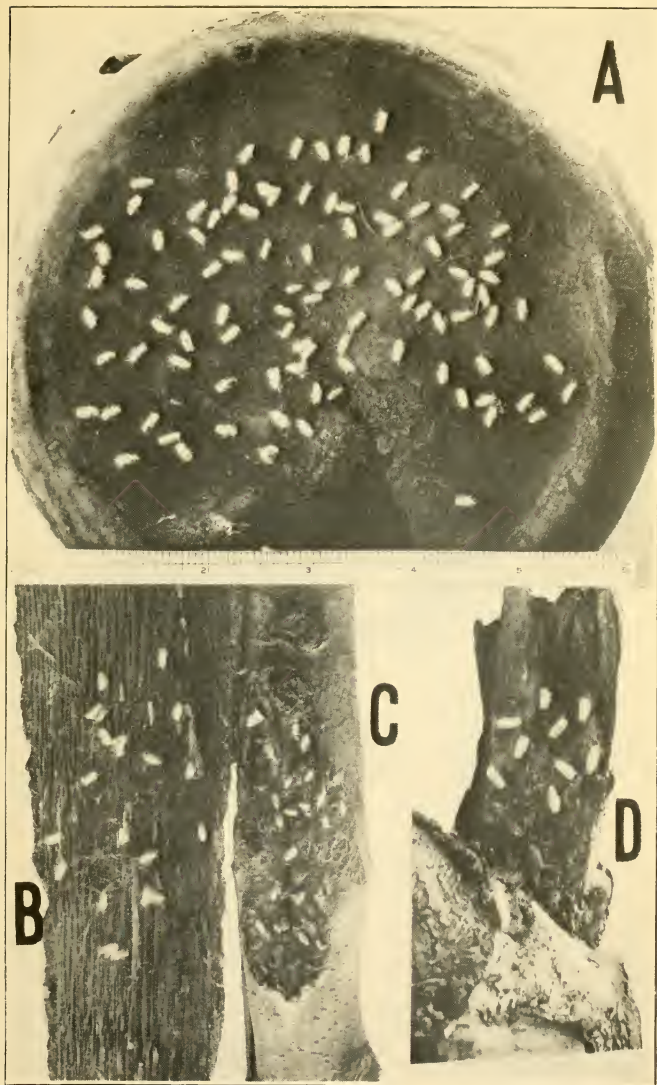
APANTELES MELANOSCELUS.

A, adult female; *B*, egg, dissected from female; *C*, egg, after 15 to 20 hours in host; *D*, egg, after 48 hours in host; *E*, first-stage larva and shriveled eggshell from which it came, 50 hours after oviposition; *F*, first-stage larva; *G*, second-stage larva; *m*, molted skin, *p*, caudal horn, *a*, anal vesicle; *H*, third-stage larva, dissected from host; *a*, anal vesicle; *I*, third-stage larva, hibernating form, dissected from cocoon; *J*, first-stage larval mandible; *K*, second-stage larval mandible; *L*, third-stage larval mandible. All much enlarged.



APANTELES MELANOSCELUS.

A, Hibernating cocoons on board found in Melrose, Mass., 1917; *B*, first-generation cocoons on branch collected at Quincy, Mass., 1920; *C*, first-generation cocoons on branch collected at Melrose, Mass., 1916; *D*, first-generation cocoons on branch collected at Quincy, Mass., 1920; *E*, third-stage maggot two-thirds of its way out of fourth-stage gipsy-moth larva; *F*, third-stage maggot dissected from host, anal vesicle still evaginated.



APANTELES MELANOSCELUS.

A, Hibernating cocoons on underside of vessel collected at Weymouth, Mass., 1920; *B*, hibernating cocoons on underside of bark collected at West Boylston, Mass., 1920; *C*, hibernating cocoons on underside of branch collected at Hingham, Mass., 1920; *D*, hibernating cocoons on stump collected at Melrose, Mass., 1916.

The heart, nervous system, and silk glands are more pronounced, especially the latter, which are coiled and recoiled and appear to fill much of the body cavity. Traces of the tracheal system are observed during the last part of the stage.

Development is rapid and in two or three days the maggot has increased in size to 4.5 mm. long and 1 mm. wide.

The average period spent in this stage by the first-generation larva is from two to three days and for the second generation from five to seven days. Just before molting the mandibles of the third-stage maggot can be seen.

THIRD-STAGE LARVA.

The period spent by the third-stage maggot (Pl. I, H) within its host varies from a few hours to two days with the spring generation and as long as three days with the summer generation. When a second-stage maggot is about ready to molt it usually works its way to the central part of its host and molts there, although occasionally third-stage larvæ are found in the caudal end of the caterpillar. Just before issuing the maggot is 5 to 7 mm. long, is slender, and tapers toward the anterior end; it is dull white and dorsally is sparsely covered with very fine, inconspicuous hairs. At the caudal end of the body the anal vesicle is still evaginated (Pl. I, H at A; Pl. II, F). The body is apparently filled with the silk glands and has a well-developed tracheal system, with eight pairs of spiracles visible. There is a pair on the second segment and a pair on each of segments 4 to 10, inclusive. The spiracles are very tiny and difficult to determine, the last seven pairs being associated with laterally protruding areas. On the eleventh segment there is a slight protruding area laterally which may contain a spiracle, but one was not observed on this segment. The mouthparts are plainly visible, consisting of labium, labial palpi, labrum, maxillæ, maxillary palpi, and mandibles. The mandibles (Pl. I, L), which are 0.26 mm. long, are strong and well fitted for tearing. They are slightly curved anteriorly. The tip is divided into two sharp teeth. The anterior third of the mandible appears to be double with two biting edges, each edge armed with several teeth. There are dorsally on this part of the mandible two elevations which appear to strengthen the organ. The tips and points of the teeth are more heavily chitinized than the rest of the mandible.

When ready to issue the maggot tears a hole in the side of the caterpillar, usually in the fifth or sixth segment. When it has issued to about two-thirds its length it begins to form its cocoon (Pl. II, E). By the time the larva is entirely out, the anal vesicle has been invaginated. If the larva is of the spring generation, it voids the accumulated waste material of the larval stages after 18 to 20 hours in the cocoon. In about two days after completion of the

cocoon the maggot pupates and casts its larval skin, which is pushed back to the posterior end of the cocoon over the previously voided material.

The third-stage maggot (Pl. I, I) of the summer generation has quite a different cycle. After having completed its cocoon, in which it is to hibernate, it becomes shorter and stouter, measuring about 4 mm. in length. It is a pale lemon yellow, and remains quiescent until the following spring. About the time when the first gipsy moth eggs hatch, the maggot resumes activity, first voiding the accumulated waste in the caudal end of the cocoon. Two or three days later pupation takes place, and the larval skin is cast and pushed to the caudal end of the cocoon, as in the spring generation.

PUPA.

The pupal stage lasts from five to nine days. About two days after the completion of the cocoon the larval skin is cast. The pupa is whitish with long appendages and has a movable abdomen. The eyes soon begin to darken, the ocelli are distinguishable, and the thoracic and abdominal segments take form. The mouth parts, antennæ, legs, and recurved ovipositor are plainly seen. In three or more days the development is complete. The whole is now dark, nearly black. The pupal skin is cast and the adult lifts the cocoon cap, having cut around its base, which was left weak by the spinning larva.

COCOON.

When the third-stage maggot is about two-thirds of its way out of the host, it begins to construct its cocoon. The first few threads seem to be attached ventrally to the maggot itself on the last segment which is outside of the caterpillar. After making an attachment at this point the maggot straightens out horizontally, then swings back underneath itself again and makes another attachment. It continues this process laterally and dorsally, spinning all the while and forming loops which it gradually fastens securely in a similar manner. As the outer loose cocoon is developed, the maggot must break away from the original attachments and gradually work itself entirely free from its host. The maggot reverses its position several times during the construction of the cocoon. When completed, the cocoon is about 5mm. long and is composed of an outer loose covering of fine threads, some of which are attached to the host or any object on which it may rest. Just within this is a tough, tightly woven envelope, which encases a very fine smooth inner sac next to the maggot. The cocoon is slightly flattened on its ventral surface and convex laterally and dorsally. The anterior end is rather flat. The cap, which is thinner along its base, is at the anterior end. The posterior end is slightly pointed. It takes the spring-

generation maggot about two hours to form its cocoon and the summer maggot three to four hours to complete the cocoon in which it is to hibernate.

The cocoon made by the spring-generation maggot is pale yellowish white, a little smaller and rather delicate as compared with the hibernating cocoon, which is a light sulphur yellow and very tough.

LOCATION OF COCOONS.

The cocoons of the spring generation are found singly or in clusters, depending upon the degree of gipsy moth infestation and the abundance of *Apanteles*. In low growth the cocoons are very apt to be found on the foliage and often on the débris on the ground, as well as along the trunk and small branches. On large trees a few cocoons are found on the foliage, but if abundant the majority are located at the junction of the smaller branches on the underside. The cocoons are attached lightly, often on top of others and invariably a dead second-stage gipsy moth larva is found with each cocoon (Pl. II, B, C, D). After the adults have issued these cocoons are easily washed or blown from the trees and are seldom found the next spring.

The second-generation cocoons are found securely attached scatteringly over the tree trunk and in clusters under the larger limbs where the gipsy-moth larvæ congregate. These cocoons are not often found on the foliage.

The gipsy-moth larvæ, when parasitized by the second generation of *Apanteles melanoscelus*, have a tendency to crawl to protected and out-of-the-way places just before the issuance of the parasite maggots. The cocoons are often associated with the gipsy-moth pupæ and larger caterpillars. They are found behind billboards and signs, attached to trees (Pl. III, D), on the undersides of boards on the ground (Pl. II, A), under fence rails or rocks, under loose bark, and on rough surfaces on the underside of limbs (Pl. III, B, C). Plate III, A, shows a tin vessel found during the summer of 1920 in a dump at Weymouth, Mass., and illustrates the habit of parasitized larvæ of crawling to hidden places. There are a few over 100 cocoons on the bottom of this vessel, and there is a cluster of 25 cocoons on one side of the vessel not shown in the photograph.

SEASONAL HISTORY.

The seasonal history varies considerably with the season. The issuance of adults of *Apanteles melanoscelus* from their hibernating cocoons begins about the time of maximum hatch of the gipsy-moth eggs, which is usually near the middle of the second week in May. During such a season most of the *Apanteles* will have issued by May 20. Under field conditions females of *Apanteles melanoscelus* do not

begin to oviposit immediately, for the bulk of issuance of the spring generation parasite maggots is around June 12. The adults which develop from these maggots will be found issuing from 7 to 11 days later. Cocoons of the second generation, or those in which the parasite is to pass the winter, begin to appear about the fourth of July, but usually not in abundance until the second week in July.

FEEDING OF PARASITIZED LARVÆ VERSUS NONPARASITIZED LARVÆ.

Several feeding records were kept of gipsy-moth larvæ which were known to be parasite-free as checks against similar feeding records of larvæ in which *A. melanoscelus* had oviposited. The records show that healthy gipsy-moth larvæ eat from two to three times as much as those which contain parasite maggots. These data were obtained from feeding records made during the period between oviposition in the caterpillar and issuance of the parasite maggot and the checks were kept only for a similar number of days. The gipsy-moth larva from which a maggot of *A. melanoscelus* has issued eats no more, although it may live a few hours or as long as two weeks, the average being seven days.

LONGEVITY EXPERIMENTS.

The tray shown in figure 1 (p. 4) was found most satisfactory for the longevity experiments although glass tubes 8 by 2 inches were used successfully for small numbers of parasites.

The adults were fed on an equal mixture of honey and water, sprayed on small pieces of sponge. It is important that the sponges should be kept clean by thoroughly washing every other day. Nothing but the food was inclosed in the trays with the adults, but in the tubes they did better if a crumpled bit of paper was present on which the parasites might rest and clean themselves. *A. melanoscelus* in the tubes and trays, if kept in the light, lived for about one week. When the containers were kept darkened by means of black paper, the parasites remained rather inactive much of the time, and lived considerably longer.

In several experiments with adults issuing in spring and summer, males and females lived for 30 to 32 days. In one case a female of the summer issuing generation lived 35 days. There was very little difference in the length of life of the adults, the females living slightly longer than the males. Without food they were able to live only a few days.

HOSTS OF *A. MELANOSCELUS*.

Ratzeburg¹¹ gives as hosts in Europe *Porthetria dispar* L. and *Stilpnotia salicis* L.

From field-collected material in this country *A. melanoscelus* has been reared only from the gipsy moth. *S. salicis*, the satin moth.

¹¹ RATZBURG, JULIUS THEODOR CHRISTIAN. OP CIT. 1852.

recorded as a host of this parasite in Europe, was not found in America until the latter part of June, 1920, when a heavy infestation was discovered at Medford, Mass. When the infestation was found the larvæ were from half to full grown and rather too large to be expected to harbor *A. melanoscelus* maggots. Collections of larvæ were made immediately, but no *A. melanoscelus* were reared. On several occasions, however, cocoons of this species were found on tree trunks closely associated with belated larvæ of *Stilpnotia salicis*, and there is very little doubt that these cocoons were spun by *A. melanoscelus* maggots which had issued from the near-by small and inactive larvæ of *S. salicis*. It is known that with the gipsy moth the larvæ from which *A. melanoscelus* maggots issue do not die for several days. They are rather inactive and often do not move far from the place where they were when the parasite issued.

In August, 1920, an outbreak of *Hemerocampa leucostigma* S. & A. was located in a small area in Somerville, Mass. This is the first time since *A. melanoscelus* has been established that larvæ of the white-marked tussock moth could be collected in eastern Massachusetts, except very sparingly. The season was too far advanced to expect to rear *A. melanoscelus* from collected material, and none were recovered from larvæ brought to the laboratory. It was apparent, however, from observations made at the infestation, that this parasite had been responsible for the untimely death of very many tussock-moth larvæ, for the cocoons of *A. melanoscelus* were abundant on the sheathing of near-by houses where the tussock-moth larvæ had gathered in large numbers and were spinning their cocoons.

Several experiments were tried confining adults of *A. melanoscelus* with various larvæ. Reproduction was successful with *Malacosoma americana* Fab., *M. disstria* Hübn., *Hemerocampa leucostigma* S. & A., *Olene basiflava* Pack., and *Euproctis chrysorrhoea* L. The female attacked all but the last eagerly. Oviposition apparently took place in *Charidryas nycteis* D. & H., *Hemileuca maia* Dru., *Pteronotus ribesii* Scop., and in a species of tortricid. All of these larvæ died and were dissected. Several maggots of *A. melanoscelus* were found in the larvæ of *C. nycteis*, but no evidence of parasitism was found in the other larvæ.

Several larvæ of *Stilpnotia salicis* were presented to females of *A. melanoscelus*. No oviposition was recorded. This was late in the season and the larvæ had matured much beyond an attractive stage for oviposition by this parasite.

Some six or seven species of smooth-skinned or hairless larvæ have been confined with females of *A. melanoscelus* but rarely have they shown any attention to them. This parasite evidently will attack quite a number of small hairy lepidopterous larvæ when the oppor-

tunity presents itself, but shows very little interest in large hairy caterpillars or in larvæ which are destitute of hair or only sparsely covered.

PART II.—INTRODUCTION AND ESTABLISHMENT.

EUROPEAN WORK.¹²

In January, 1911, Mr. W. F. Fiske, who was at that time in charge of the parasite work under the direction of Dr. L. O. Howard, Chief of Bureau, sailed for Italy to investigate the parasite situation. The main object at that time was to make a study of conditions there and to attempt to introduce on a large scale *Chalcis flavipes* Panz., a pupal parasite of the gipsy moth. Headquarters were located at Naples and a vacant building was rented and fitted up for use as a laboratory near the School of Agriculture at Portici.

Early in February, 1911, Mr. Fiske visited several places in Sicily to ascertain the field conditions and degrees of gipsy moth infestation preliminary to obtaining the *Chalcis* material. While there he discovered that cocoons of a species of *Apanteles* were present in "countless thousands." This came very much as a surprise, and he determined to put most of his energies, even at the expense of previous plans, into an effort to send this parasite to America in as large numbers as possible.

The localities, a forest at San Pietro, Caltagirone, and the forests back of Barcellona, in Sicily, were situated where the gipsy-moth larvæ and cocoons were sufficiently abundant to warrant the collection of either in large numbers. Both places were some distance from a railroad, and the location which gave more promise was the less accessible of the two. As soon as the gipsy-moth larvæ had hatched and were of sufficient size to have been parasitized, collections of larvæ were begun. A foreman and crew were located at each place, and the collections of larvæ were started. The first larval collection arrived from Caltagirone at Portici on May 14, and a few cocoons were present at that time. When the collections arrived at Portici they were placed in trays in the house which was rented for that purpose. About a dozen Italian girls took care of the trays—that is, fed the caterpillars, removed the parasite cocoons daily, and kept the trays clean. These girls were very adept at this work, being familiar with the care of silkworms and having assisted in handling alfalfa weevil parasite material for shipment to America.

As soon as the cocoons were removed from the trays they were placed in cold storage to prevent the further development of the parasites.

¹² The part of this report pertaining to European work is based on the correspondence of Mr. W. F. Fiske while in Europe.

The tray work was supplemented by collections of the cocoons in the field and these had to be iced to prevent as much as possible any issuance of secondary parasites, as well as to retard the development of the maggots of *Apanteles melanoscelus*. When the cocoons arrived at Portici they were usually picked over and repacked, although it was not possible to do this in all cases.

The shipments depended largely on the supply of parasite material on hand and the dates of departure of vessels to America; but the policy followed was to ship as often as possible.

Several types of containers were used for transporting the cocoons, all of which came in the vessels' cold storage and all proved quite satisfactory. One type of refrigerator was so made that the small packages of cocoons of *Apanteles* in the inner chamber were entirely surrounded by ice. This refrigerator was a double-walled affair and rather expensive to construct. It was inclosed in a box of sawdust. Another type was a sort of ice-cream freezer arrangement consisting of two metal water-tight cylinders, one within the other, with the cocoons in containers packed in sawdust within the inner cylinder. Ice was packed between the two cylinders and the whole was packed in sawdust in a large wooden box. At the bottom of the outer cylinder was a small pipe which went through the box and allowed the water to drain off. On some occasions the containers were repacked with ice in New York before being forwarded to Melrose. A few shipments of cocoons which were merely packed in boxes, and kept in cold storage for as much of the trip as possible, came through in good condition.

COMPARISON OF SEASONAL HISTORY IN SICILY AND NEW ENGLAND.

The spring of 1911 was cold, rainy, and rather backward in Sicily. By May 15, however, parasite maggots had begun to issue from the gipsy-moth larvæ. The earliest record for issuance of maggots for New England is May 22. It is likely that during many seasons in Sicily maggots issue by May 7, whereas the New England record referred to is an early one, issuance of maggots usually beginning the last of May. This would make the season in Sicily about three weeks earlier than at Melrose Highlands, Mass. The second-generation cocoons were being collected in Sicily by June 10, 1911, but June 23 is the earliest record of the presence of this generation in New England.

ABUNDANCE OF *A. MELANOSCELUS* IN SICILY.

The parasite cocoons were very abundant in places as indicated in notes and correspondence received from Mr. Fiske.

Apanteles killed more caterpillars than all of the other parasites put together. Cocoons average 1,000 to a tree, not counting the smaller trees.

Notes made at another place state:

Apanteles exceedingly common. Estimate 75 per cent control on average and higher in some places. Estimate 10,000 cocoons on one large tree.

To illustrate the abundance of cocoons, those present on an area the size of a man's hand were counted and the number found was 187. Mr. Fiske states that there were more over a similar area high up on the tree. The same day he visited another place and found conditions similar.

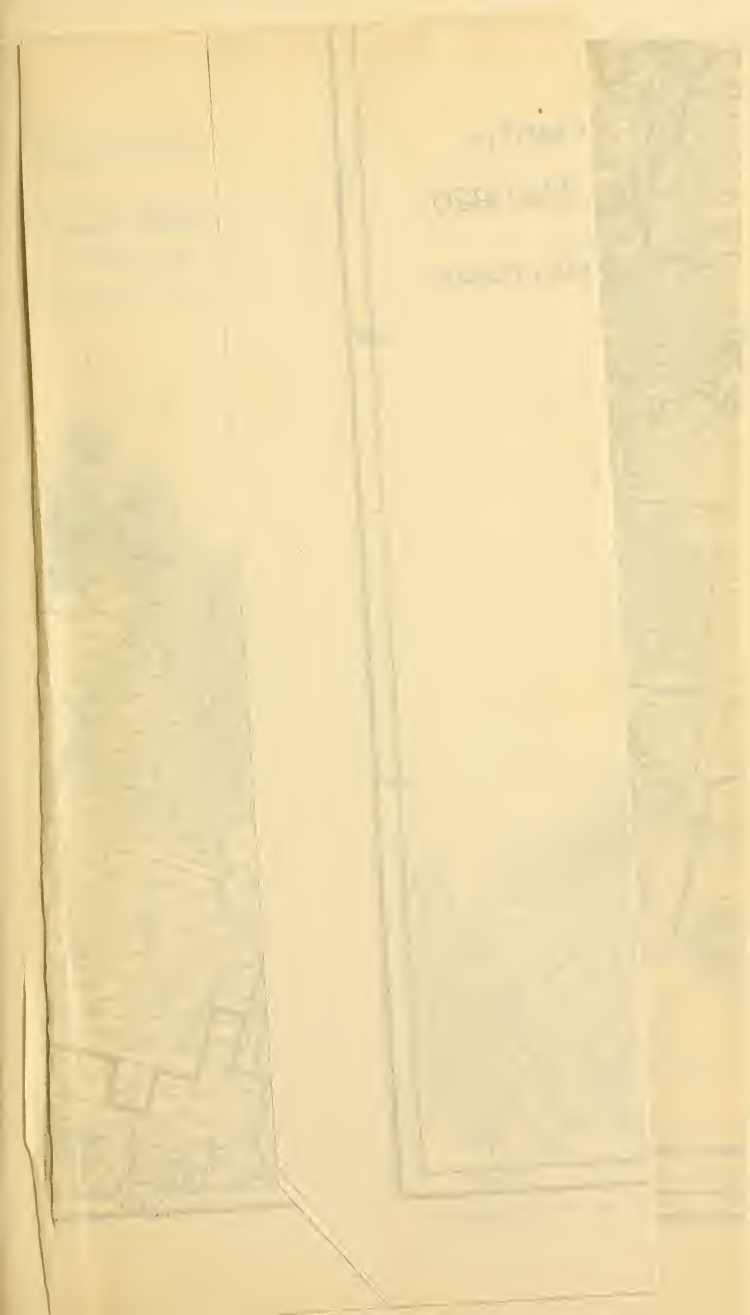
SECONDARY PARASITISM IN SICILY.

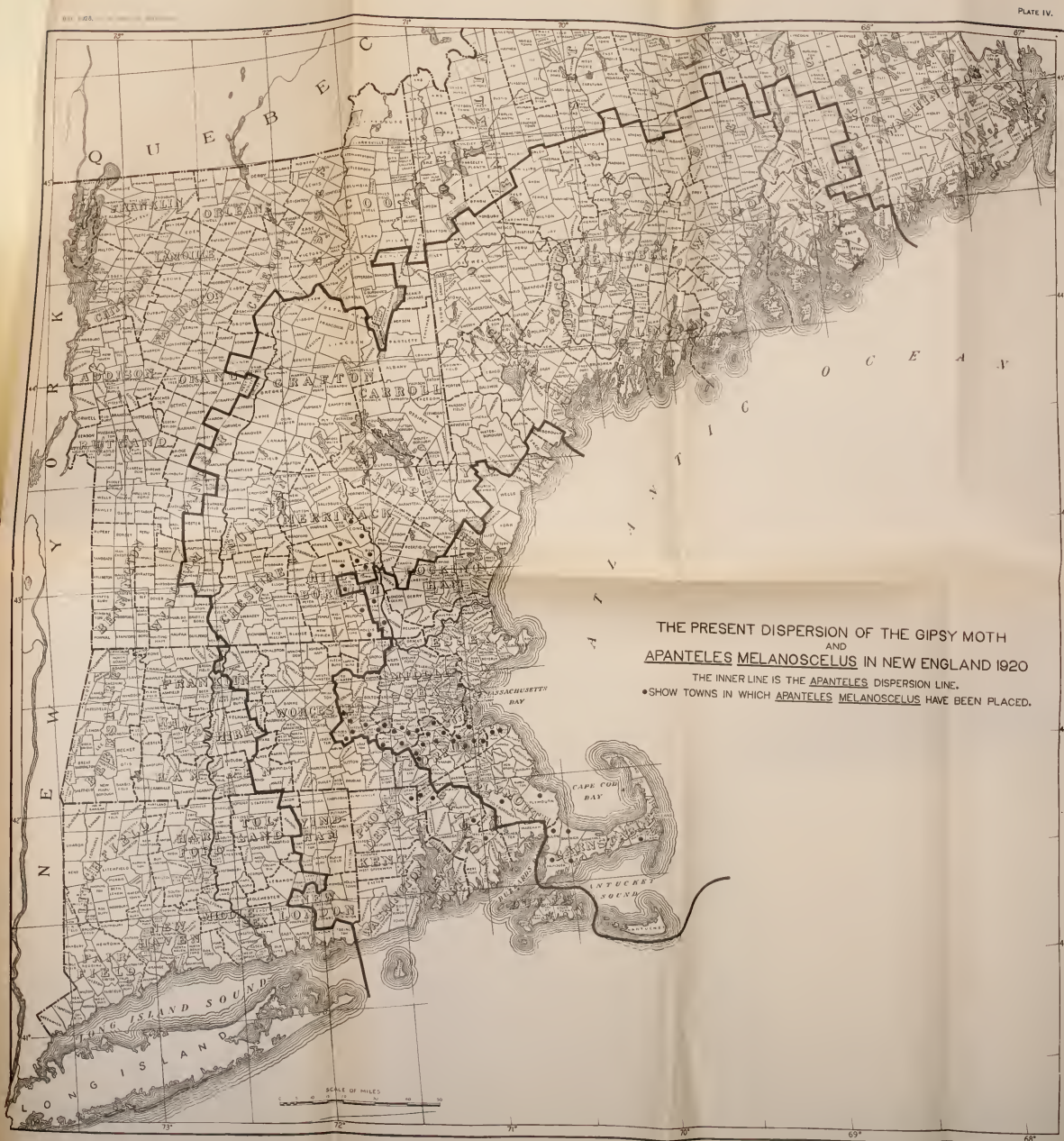
Apparently the first-generation cocoons are not attacked seriously by secondaries, probably less than 10 per cent being killed. Secondary parasitism of the hibernating cocoons is very heavy, and one note was found referring to a location where it was feared that it would almost exterminate the parasite. Sometimes as high as 75 per cent of the cocoons from Sicily received at the laboratory and wintered were killed by secondaries.

COLONIZATION IN NEW ENGLAND.

During the rush of the season's work it was supposed that two or three species of *Apanteles* were represented and the importation and colonizations were recorded in correspondence and in the notes as *A. solitarius* and *Apanteles* II and III. The confusion was not at all surprising for there were two and possibly three species represented, but the fact of the matter, as it appears at the present time, is that the adults liberated during June, 1911, at North Saugus, Mass., from cocoons imported from Sicily as *A. solitarius*, were adults of the first generation of *A. melanoscelus*; and that the cocoons received later in the summers of 1911 and 1912, which were hibernated at the laboratory, and the adults from which were liberated at Melrose during the springs of 1912 and 1913, were cocoons of the second generation of *A. melanoscelus*.

During June, 1911, about 125,000 cocoons of the first generation were received from Europe, and every precaution was taken to prevent the escape of any secondaries which might be present. As soon as they were received at the laboratory they were taken to North Saugus, Mass., and immediately placed in darkened containers from which nothing could escape except by entering glass tubes, where they were inspected, the good allowed to escape and the bad destroyed. In this manner 23,000 adults were liberated during June and July, 1911. During the months of July and August, 1911, nearly 17,000 hibernating cocoons were received. These were isolated at the Melrose Highlands laboratory, each one being placed in a small gelatin capsule and then wintered under outdoor conditions.





THE PRESENT DISPERSION OF THE GIPSY MOTH
AND
APANTELES MELANOSCELUS IN NEW ENGLAND 1920

THE INNER LINE IS THE APANTELES DISPERSION LINE.

• SHOW TOWNS IN WHICH APANTELES MELANOSCELUS HAVE BEEN PLACED.



During the spring of 1912 the adults which issued from these cocoons were liberated near the laboratory.

Early in 1912 Mr. Fiske again went to Italy, this time with several assistants. As one of the results of this trip, 22,000 cocoons of the second generation of *A. melanoscelus* were received during the summer of 1912. These cocoons were collected in the forest of San Pietro, near Caltagirone, Sicily, during the week beginning June 15. They were shipped to Naples in cold storage on June 22 and held there in cold storage until all had been isolated in gelatin capsules. Early in July they were sent to America in cold storage and hibernated at the laboratory. The adults which issued in the spring of 1913 were liberated at Melrose.

Table 1 shows the number of individuals of *A. melanoscelus* that have been liberated in New England. The colonizations of 1911, 1912, and 1913 were adults which issued from cocoons received from Sicily; the rest of the colonization material was obtained by rearing and breeding New England material.

TABLE 1.—Number of *A. melanoscelus* liberated in New England, 1911–1920.

Year.	Number of adults liberated, Sicilian material.	Cocoons colonized, New England material.	Number of colonies placed in Massachusetts.	Number of colonies placed in New Hampshire.	Number of colonies placed in Rhode Island.	Total number of colonies.
1911.....	23,000	.....	1	.....	.....	1
1912.....	203	.....	1	.....	.....	1
1913.....	273	.....	1	.....	.....	1
1915.....	.....	1,500	2	1	.....	3
1916.....	.....	5,541	11	.....	.....	11
1917.....	.....	3,500	7	.....	.....	7
1918.....	.....	8,100	9	7	.....	16
1919.....	.....	930	2	.....	.....	2
1920.....	.....	10,100	11	9	1	21
Total.....	23,476	29,671	45	17	1	63

As will be seen from a study of the figures in Table 1, very few adults were liberated in 1912 from the 17,000 cocoons received in 1911, and in 1913 from the 22,000 cocoons received in 1912. The poor issuance from these imported cocoons was due to several factors. Fifty to seventy-five per cent were killed by secondaries and a few were injured while being collected. These cocoons were kept in gelatin capsules from the middle of the summer until the adults issued the following spring. Subsequent experiments have shown that the mortality of hibernating larvæ of *Apanteles melanoscelus* was not so high when the cocoons were isolated in small glass vials plugged with cotton batting as when they were kept in gelatin capsules. An examination of dead maggots of *A. melanoscelus*, which had been isolated in gelatin capsules, showed that the maggots were

very dry and shriveled, and indicated that death might have been due to lack of moisture within the capsules.

No colonies were liberated in 1914, as no importations were made and the parasite had not been sufficiently well established to furnish colonization material.

All *Apanteles melanoscelus* liberated since 1913 have been put out while in the cocoon and have been of the summer-issuing generation. Most of these colonies have contained 500 cocoons. In liberating a colony the cocoons are taken to the field and emptied into a small cylindrical can, which is then nailed to a tree in an inconspicuous place. A cover is placed on the can to protect the cocoons from rain and birds. The adults escape through three $\frac{1}{4}$ -inch holes punched in the can near the top. The size of the can is not especially important, but a convenient can used at the laboratory is 3 inches in height and 2 inches in diameter. It is necessary to place a band of tree-banding material entirely around the can to prevent ants from destroying the colony.

In selecting sites for colonies, woodland areas with a light to medium gipsy-moth infestation are preferable. Heavily infested territory which is apt to be stripped of its foliage should be avoided.

After the colony has been liberated a roadside tree is marked in white paint with an arrow pointing to the colony and the letters A. M. In the woodland near the exact spot of the colony a tree is banded with white paint. These field marks are made so that the place can be found later if desired. At the same time a numbered note is written for the laboratory files which explains the condition at the colony site and gives directions for finding the colony.

The colonies have been placed in groups of towns, one colony in each town, as shown in the accompanying map (Pl. IV). This method of liberating colonies was used because the parasite disperses rapidly and there was considerable chance that small colonies would not become established if they were placed singly at widely separated locations. In this way several rather large areas, from which the parasite can spread to the surrounding towns, have become well stocked.

METHODS USED TO OBTAIN MATERIAL FOR COLONIZATION.

The story of the introduction of *A. melanoscelus* and the colonies liberated from the imported material has been recorded earlier in this paper. Two methods have been used to get material for colonization since the establishment of the parasite in New England—first, by rearing the parasite from field-collected gipsy-moth larvæ, and, second, by breeding the parasite at the laboratory.

The first method consists merely of making collections of large numbers of second-stage gipsy-moth larvæ from locations where the parasite is present in sufficient numbers to warrant such collections.

These larvæ are placed in trays and fed until the parasite maggots issue. The maggots, upon issuing, spin their cocoons, usually attached to the caterpillar or to the object on which the host was resting at time of issuance. Each day the gipsy-moth larvae are fed, the trays cleaned out, and all of the parasite cocoons removed. The cocoons are put up in lots of 500 and kept in a refrigerator until they are placed in the field. They are colonized as soon after removal from the trays as possible, usually on the following day. Occasionally it has been necessary to keep the cocoons in the ice chest five or six days, and this has been done without any apparent injury to the parasite.

The second method of securing material for colonization may be divided into two parts, namely, the fall work which consists of gathering and caring for the hibernating cocoons, and the actual breeding work which is carried on in the spring. There is a great mortality of wintering *A. melanoscelus*, largely due to secondary parasitism, and a large number of cocoons must be gathered in order to have a few adults of *Apanteles* in the spring to start the breeding work. The cocoons are collected as soon as possible after they have been found, in an endeavor to get them before the secondaries or ants do.

From 10,000 to 20,000 cocoons are collected during July from places where the parasite is abundant. Some of the secondaries present at this time hibernate within the cocoon, but there are many which have one or more generations during the early fall.

For a number of years these cocoons were isolated in gelatin capsules as soon as they arrived at the laboratory. This prevented the issuing secondaries from doing any further damage, but it was found that the spring issuance of *A. melanoscelus* from apparently good cocoons was exceedingly small. This was due partly to secondaries which hibernate within the cocoons, partly to injury while handling, and considerably to the drying of the maggots of *A. melanoscelus* in the cocoons. The last two years the cocoons have not been isolated, with the result that a better spring issuance has been obtained. Instead of isolating the cocoons they were separated into lots of 100 each and placed in glass tubes 1 by 4 inches, which were plugged with cotton batting. These tubes were then placed on a background of white in a warm bright place where they could be watched and the secondaries were removed as fast as they issued. Most of the secondaries issuing in the summer leave the cocoons within two weeks after collection, although a few continue to issue for two weeks longer. After the secondaries have stopped issuing the cocoons are picked over and the empty ones and those showing external injury are discarded. Many of the cocoons which contain hibernating secondaries at this time can be distinguished by a slight discolored spot on the cocoon; such cocoons also are destroyed. The

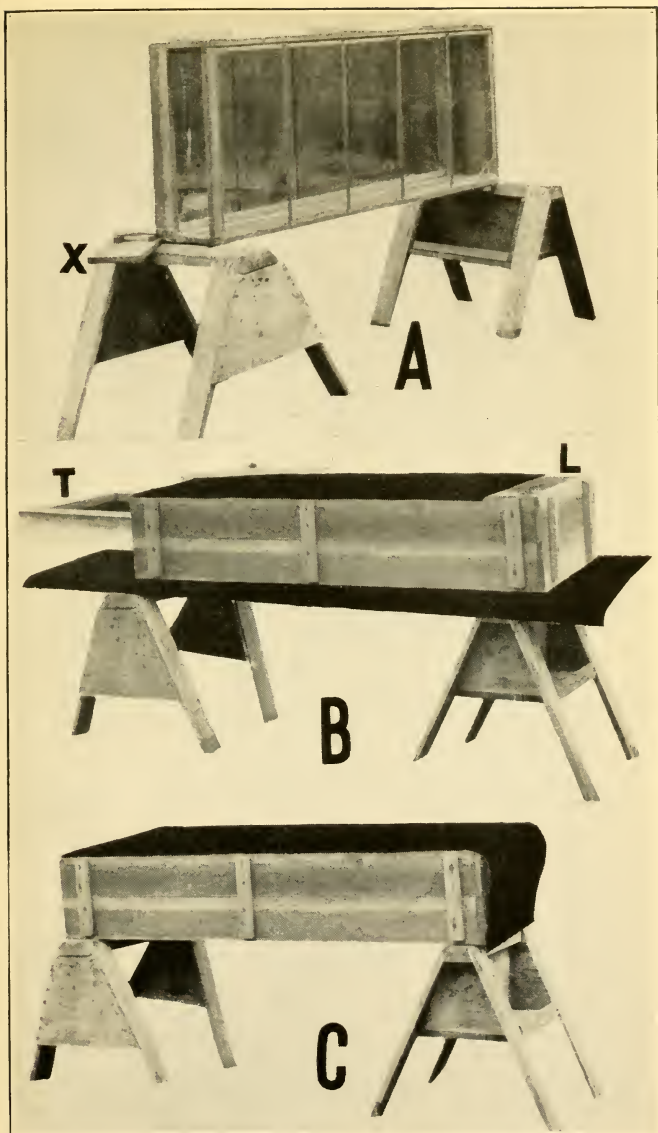
remaining cocoons are placed in bulk in a fine copper-wire cage which is nailed in a protected place in the yard until spring.

The spring work begins during the last of April when the cocoons are removed from their hibernating cage and isolated for a short period in capsules. They are isolated at this time for convenience in handling the adults of *Apanteles* and destroying the wintering secondaries which issue. The cocoons are isolated in the capsules less than two weeks before *A. melanoscelus* begins issuing, and this short period of confinement does not have a detrimental effect. As the adults emerge they are removed hourly from the capsules and placed in glass tubes 8 by 2 inches. The sexes are kept separate. A sponge dampened with a mixture of equal parts of honey and water is placed in each tube. The tubes are then placed in a cool, dark place until ready for use.

Several different types of cages and trays have been tried as breeding chambers with varying degrees of success. *A. melanoscelus*, like most hymenopterous parasites, is extremely heliotropic and individuals are found resting on the sides or top of the container or exhausting themselves flying about the source of light. During the past summer a breeding chamber was devised which eliminated the unsatisfactory light conditions of previous cages (Pl. V, A, B, C). This type of breeding chamber should prove of value in breeding work with other parasites.

The empty chamber is shown in Plate V, A, resting on one side. It is merely a wooden case with a glass bottom and top, with an opening left in one end, through which the tray containing the larvæ to be parasitized is admitted. The opening is just wide enough to allow the introduction of the tray and is about 2 inches deeper than the tray. Cleats on which the tray is to rest are arranged inside the chamber about 2 inches from the bottom. The tray should fit closely to the sides and ends of the chamber, but not tightly enough to bind when being introduced or removed. After the tray has been put in place the opening in the end of the cage is closed with a tightly fitting board (Pl. V, A at X).

When the chamber is to be stocked with the parasites it is placed on a flat surface which has previously been covered with black paper (Pl. V, B). A piece of black paper is laid over the top, covering all but 6 or 7 inches of the glass at the end of the chamber facing the sun (Pl. V, B at L). The parasites are liberated in the cage and fly to the uncovered part of the chamber where they gather on the glass top. The tray containing the small caterpillars is slid into place and is shown, part way in, in Plate V, B at T. The open end of the chamber is now closed and the whole thing is removed to two wooden horses, as shown in Plate V, C. A piece of black paper is now placed over the entire top.

**APANTELES MELANOSCELUS.**

A. Breeding chamber resting on its side; *x*, Board to close open end; *B.* Chamber ready to stock with parasites and gipsy-moth larvae. Tray containing gipsy-moth larvae shown at *l*, part way in; the light is admitted at *l*. *C*, chamber resting on horses, with light entering from bottom only.

With this arrangement all of the light entering the chamber comes from beneath, through the glass bottom of the chamber and through the cloth-covered bottom of the tray. Five minutes after the chamber is in this position practically all of the *Apanteles* have left the top of the chamber and are found dispersed over the bottom of the tray, where the gipsy-moth larvæ are feeding and crawling. The parasites begin ovipositing in the caterpillars immediately after they have been attracted to the bottom of the tray.

When the caterpillars have been exposed to *Apanteles melanoscelus* for a sufficient period the operations are reversed; the chamber is placed on a black-covered surface with the end of the chamber opposite the end where the tray is to be removed, facing the sun. Light is now admitted by removing the black paper over a space of 6 or 7 inches, as shown in Plate V, B at L. In a few minutes most of the parasites will congregate in the top of the chamber at the light end. The opposite end of the chamber can now be opened without danger of any of the parasites escaping. The tray is withdrawn slowly, care being taken that all of the *Apanteles* have left it. If any still remain, they will fly to the light end of the chamber when disturbed by touching them with a small camel's-hair brush.

As soon as the tray has been removed another one is introduced and the process is repeated as long as the supply of *Apanteles melanoscelus* lasts. The larvæ parasitized in this manner are fed in the trays until the parasite maggots issue. The resulting cocoons are removed each day for colonization.

A breeding chamber stocked with 300 adults of *Apanteles melanoscelus*, with the sexes equally divided, can be used about one week. Each tray should contain about 10,000 first-stage gipsy-moth larvæ.

The period of exposure of the larvæ to the parasites varies with the temperature and time of day. The parasites are most active during the middle of the day. The larvæ were enclosed in the chamber about two hours during this part of the day. Earlier in the morning and later in the afternoon the larvæ were exposed for about three hours. An average of about 1,000 parasite cocoons were removed from each tray. Undoubtedly many more than a thousand larvæ were parasitized in each tray, but there is always a certain amount of unavoidable mortality of first-stage larvæ in feeding trays. Many of the larvæ are weak and do not get to the food and many are injured when the trays are cleaned and the larvæ fed.

SUCCESS OF COLONIES AND DISTRIBUTION OF A. MELANOSCELUS.

Records of the success or establishment of colonies liberated and of the distribution of the parasite are obtained by collecting host material from the field and rearing the parasite from these larvæ at the laboratory, or by collecting the cocoons of the parasite in the field.

Often the parasite is recovered the year following colonization. *A. melanoscelus* has been recovered from all but one of the colonies liberated previous to 1918. It has been recovered from half of the colonies put out in 1918 and from both of the colonies liberated in 1919. Recoveries of the parasite were made late in the summer of 1920 in a few of the towns which were colonized during June of that year.

DISPERSION.

The inner black line on the map (Pl. IV) shows the present known distribution of the parasite in New England, it having been recovered from practically every town within this line. It is probable that in some cases *A. melanoscelus* has spread beyond the line indicated, for many of the towns just outside of the dispersion line have not been scouted.

It is rather difficult to determine the exact distance the parasite will spread in a year, for when the parasite is scarce its recovery is largely a matter of chance. The number of host larvæ which it is practical to collect in an endeavor to rear the parasite for dispersion records is infinitesimal when compared with the larvæ present in a town. Scouting for the cocoons is more satisfactory, but this is not infallible, and the fact that a town may have been scouted and no cocoons found does not prove that the parasite is not present.

The recovery records show that the greatest spread of this species has been to the north and northeast, similar to the dispersion of the gipsy and brown-tail moths. The data obtained indicate a spread of about 25 miles a year in this direction. During the summer of 1918 there were two recoveries made which because of their locations are of special interest. One of these recoveries was made at Provincetown, which is 25 miles northeast of Harwich, where the nearest colony of *A. melanoscelus* was liberated in 1915. The other recovery was made on the island of Nantucket, which is 25 miles south of the Harwich colony. In 1915 a colony of *A. melanoscelus* was liberated in Middleboro, about 33 miles southwest of Provincetown. The colonies at Harwich and Middleboro were the only ones that had been liberated in that part of the State. These recovery records can not be taken as absolute proof of a flight of 25 miles for the insect, as it is possible that cocoons of the parasite were taken to Provincetown and Nantucket on cordwood or other material. This does not seem likely, however, for the parasite was not recovered from any of the other towns in southeastern Massachusetts until 1919. The number of cocoons taken at Provincetown and Nantucket in 1918 indicated that the parasite had been present in both places for 1 year at least.

SECONDARY PARASITISM.

Cocoons of the first generation are not seriously attacked by secondary insects. Small collections of cocoons of this generation are made each year over a considerable area and rarely are they parasitized over 10 per cent; more often not more than 2 or 3 per cent are killed by secondaries.

Unfortunately it is a different story with the hibernating brood, for approximately 75 per cent are killed annually by native secondary insects and ants. This seriously handicaps the increase of *A. melanoscelus*. Among the insects which have been reared from the hibernating cocoons are at least three Ichneumonidae, and members of the Pteromalidae, Elasmidae, Eurytomidae, Entedontidae, and Eupelmidae. In this complex there are secondary, tertiary, and possibly quaternary and quinquenary insects. An investigation of the life histories and host relationships of these insects has received considerable attention at the laboratory, but has not been completed. Some of these insects have several generations during the early fall and then hibernate within the cocoons of *A. melanoscelus*.

THE VALUE OF *A. MELANOSCELUS* AS A GIPSY MOTH PARASITE.

The problem of obtaining the actual percentage of parasitism of the gipsy moth by *A. melanoscelus* or by any of the other introduced parasites, except the egg parasites, is a difficult and complicated matter involving many factors. Records at the Gipsy Moth Laboratory show that larvæ picked promiscuously from tree trunks and foliage to-day may give 30 per cent parasitism, while to-morrow the same number of larvæ, collected by the same individual, in the same manner, and in the same locality, may not even show the presence of the parasite.

For a number of years collections of gipsy-moth larvæ have been made daily through the entire larval period at Melrose and Stoneham, in an attempt to learn the true status of the parasites in that section. Each collection contained 100 larvæ all of the same stage. The collections of each stage were continued as long as that particular stage could be found, and collections of the next stage were started as soon as 100 larvæ of the next stage could be found. As there is quite an overlapping of stages, there were very often two collections on the same date at the same place. All of the collections were kept separate and the larvæ were fed in trays until all of the parasites had issued. The trays were examined each day and any parasites which issued were removed and recorded. Individual collections, containing 100 caterpillars each, gave from nothing to as high as 40 per cent parasitism of second-stage gipsy-moth larvæ for the spring

generation of the parasite. The records of parasitism secured from fourth-stage caterpillars which represent the second or summer generation of *A. melanoscelus* were about the same.

The second and fourth stages of the gipsy-moth larvæ usually showed the highest percentage of parasitism, but a considerable number of the individuals of the other stages were killed by the parasite. Occasionally collections were made which gave as high as 15 per cent parasitism, for each of the other larval stages. In large collections of larvæ where all the caterpillars in sight were collected, the parasitism obtained averaged around 10 per cent for each generation. The collections from which these figures were secured contained from 5,000 to 20,000 larvæ.

The figures obtained from the foregoing collections should not be taken as representing the value of the parasite.

There are a great many parasitized gipsy-moth larvæ which die in the field before the parasite maggot has had time to develop. The parasitized larvæ do not eat so much as nonparasitized larvæ and are inclined to crawl to out-of-the-way places and often are not seen by the collector. On the other hand, if one should search for the hidden larvæ the collection would not be representative of conditions as they truly exist.

There is each year a high percentage of mortality of the gipsy moth, which occurs whether insect parasites are present or not. This mortality varies from year to year depending upon the conditions which influence the contributing factors, but the average percentage of mortality (barring insect parasites) for any period of years is the same as for any other similar period of years, if the periods include a sufficient number of years to make the average a fair one. This average mortality is not sufficient to prevent the increase of the gipsy moth, nor is the parasitism by *A. melanoscelus* great enough to prevent the increase of this pest. Although the exact percentage of parasitism of the gipsy moth by this parasite can not be stated, it is evident that it has a very important place as a part of the sequence of parasites which in conjunction with the other natural agencies retards the increase of this injurious insect.

ABUNDANCE OF *A. MELANOSCELUS* IN NEW ENGLAND.

Apanteles melanoscelus, like some of the other introduced parasites of the gipsy moth, is found abundantly in rather small areas. Each year since the parasite has been established these areas of abundance have been found more often and over considerably more territory. Until the summer of 1916 the parasite was not found in any appreciable numbers excepting at local points in and around Melrose Highlands. During the summer of that year a location at Beverly, Mass., was found where *A. melanoscelus* was very common. During the

same summer some interesting data were obtained from a medium-sized oak tree near the Gipsy Moth Laboratory at Melrose Highlands. This tree had many gipsy-moth egg clusters on it which had not been creosoted during the winter, so that on this particular tree there was a much heavier infestation of gipsy-moth larvæ than on any of the other trees in the vicinity. As the summer progressed, cocoons of *A. melanoscelus* began to appear in surprisingly large numbers. When most of the first-generation maggots had issued and spun their cocoons, the underside of nearly every crotch on the tree was covered with *Apanteles* cocoons (Pl. II, C).

There were 5,140 first-generation cocoons collected from this tree. A few cocoons could not be reached and some had blown away before the collection was made. Later in the season 511 second-generation cocoons were taken from the tree, making a total of 5,651 cocoons of *A. melanoscelus* removed from this tree. Although heavily infested the foliage on the tree was not damaged much by the feeding of the gipsy moth larvæ and very few gipsy-moth pupæ were found on the tree. These data are not given as a sample of the condition of the trees in Melrose Highlands in 1916, but the figures are interesting and show what happens under some conditions. Occasionally large oak trees have been seen in other towns on which it was estimated there were from 6,000 to 10,000 cocoons.

In 1918 this parasite was found in large numbers over an area of several acres of woodland in Cohasset. In 1919 and 1920 it was found abundantly in small areas in Hampton, N. H., and in the following towns in Massachusetts: Beverly, Quincy, Weymouth, Cohasset, Scituate, Marshfield, and West Boylston.

CONCLUSION.

Apanteles melanoscelus has been present in New England since 1911 and is now firmly established. It is spreading rapidly from the colonies which have been liberated and is increasing in spite of its being heavily parasitized by secondaries.

The fact that *A. melanoscelus* is able to complete its life cycle on several native insects adds considerably to its value as an introduced parasite and makes its permanent establishment more certain than if the gipsy moth were its only host.

This parasite has two generations each year on the gipsy moth and is very abundant in many small areas. It gives promise of becoming one of the most valuable of the imported parasites.

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BULLETIN No. 1032

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

Washington, D. C.

April 25, 1922

THE BLACKHEAD FIREWORM
OF CRANBERRY
ON THE PACIFIC COAST

BY
H. K. PLANK

Scientific Assistant, Fruit Insect Investigations

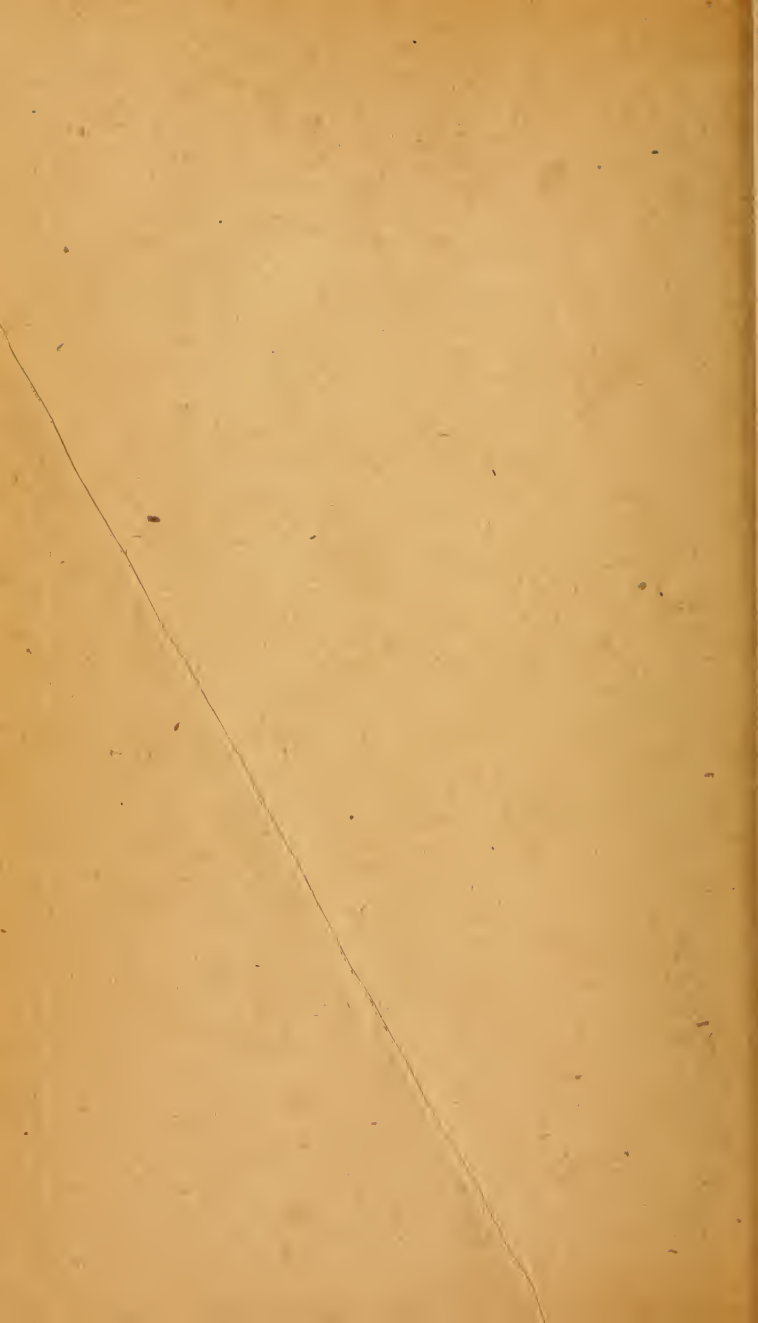
In cooperation with the Washington Agricultural Experiment Station, with
Technical Description by CARL HEINRICH, Bureau of Entomology

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THE BLACKHEAD FIREWORM¹ OF CRANBERRY ON THE PACIFIC COAST.

By H. K. PLANK,² *Scientific Assistant, Fruit Insect Investigations*, in cooperation with the Washington Agricultural Experiment Station. (With technical description by CARL HEINRICH, *Bureau of Entomology*.)

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INTRODUCTION.

Numerous complaints from Washington cranberry growers, received by the Bureau of Entomology and the State College of Washington, led the two institutions to make a cooperative investigation of cranberry pests in the Pacific Northwest in 1918 and 1919. In this joint undertaking the writer represented the Bureau of Ento-

¹ *Rhopobota naevana* Hübner; order Lepidoptera, family Olethreutidae. Determined by Carl Heinrich, of the Bureau of Entomology.

² Appointed Collaborator, Tropical and Subtropical Fruit Insect Investigations, July 1, 1920.

mology and, successively, A. Spuler, Miss Orilla Miner, and Miss Flora A. Friese the State College of Washington.

IMPORTANCE OF THE BLACKHEAD FIREWORM.

The blackhead fireworm proved to be the most important cranberry pest of western bogs, and at the time the ravages of this insect were first observed by the writer it was causing an estimated loss of approximately 40 per cent of the combined crops of Washington and Oregon. In 1918 this loss was reduced to approximately 15 per cent and in 1919 to approximately 5 per cent, principally as a result of a better knowledge of the life history and habits of the insect and more general adoption of effective methods of control.

This bulletin reports the results of an investigation of the life history and habits of the blackhead fireworm in the States of Washington and Oregon which was conducted during the years 1918 and 1919 from laboratory headquarters at Seaview, Wash. During this period various methods of control were studied and thoroughly tested under actual bog conditions.

THE CRANBERRY INDUSTRY ON THE PACIFIC COAST.

The town of Seaview, Wash., is located practically in the center of the cranberry-growing district on the Pacific coast. In the State of Washington this district comprises most of the peninsula of Pacific County, in the southwestern corner of the State, directly north of the mouth of the Columbia River. Here the industry was started on a commercial scale in the early eighties by a French gardener named Chebot, who set out about 35 acres to the McFarlin, Native Jersey, Early Black, and Cape Cod Beauty varieties. Cuttings of most of these varieties were brought in from Wisconsin, New Jersey, and Massachusetts bogs. Some cuttings, especially of the McFarlin variety, were doubtless brought in from Marshfield, Oreg., where a Mr. McFarlin had started a bog 10 years previously with his own selection of vines from the East, which bear his name. Extensive planting, however, did not take place until 1912, from which time up to 1915 large areas in southwestern Washington were drained, cleared, and made available for cranberry culture.

Approximately 700 acres of cranberries are now in bearing in southwestern Washington, with about 1,500 acres of peat land still available for cranberry culture. In Oregon and the remainder of Washington there is possibly a total of 1,500 additional acres of cranberry land, about 300 acres of which in Oregon (in Clatsop and Coos Counties) are now in bearing. Practically all the bogs of the Pacific coast are sphagnum peat of various ages and thicknesses,

found generally in swales between shore-sand ridges of slight elevation.

FEATURES OF BOG MANAGEMENT.

Although considerable water sometimes collects on the Pacific coast bogs, especially during winter, as a result of the heavy rains from September or October to April, flooding as a distinct part of cranberry bog management is rarely practiced in that section of the country. Few bogs on the Pacific coast have a good supply of water suitable for flooding purposes, and the mild winter climate in the principal cranberry-growing region seems to obviate the necessity of protecting the vines from winter injury. Principally is this true in southwestern Washington. As a consequence many terminal buds, especially on the warmer bogs, start to unfold shortly after the vines reach maturity in September and October and a certain amount of growth usually takes place during the warmer periods of the winter. It rarely happens, however, that any material damage is done by frost.

Covering the bog with water, usually from about November 15 to March 1, is practiced only to a limited extent in Oregon, but where this procedure is followed good results are usually secured. In the southern sections of the State it is almost necessary to cover the bogs with water during this period in order to keep the terminal buds from pushing forth during the warmer periods of the winter and meeting probable damage from frost during the late winter and spring.

The application of sand once every few years, as practiced on many eastern cranberry bogs, is not practiced on the coast, but probably could be employed with benefit. Inasmuch as the majority of the bogs are located between sand ridges, an abundant supply of good sand is readily available should its use become desirable.

PHENOLOGY OF THE CRANBERRY ON THE PACIFIC COAST.

The growth of the cranberry vine on the Pacific coast bogs is exceedingly variable, as will be borne out by the data presented in Table 1. This is probably because these bogs are for the most part managed as dry bogs. The relatively variable weather in that section of the country is also doubtless reflected in the early growth, blooming, and fruiting of the cranberry. It is for these reasons chiefly that no exact dates can be given for the various stages in the phenology of the cranberry in that region.

An attempt has been made, however, after a long series of frequent observations, to determine as closely as possible the approximate dates when these stages occur in their greatest abundance. These dates are presented, therefore, in Table 1 for the earliest growing varieties, such as Early Black and McFarlin, and for the latest-growing varieties, such as Howe. There seems to be considerable variation in the growth of the varieties belonging to these two classes, the height of each stage in the growth of the latest varieties generally coming a month after that of the earliest varieties.

TABLE 1.—*Phenology of the cranberry on unflored bogs on the Pacific coast, based on observations at Seaview, Wash., 1918 and 1919.*

Stage of development.	Approximate date of occurrence of the height of each stage on—	
	The earliest varieties.	The latest varieties.
Buds breaking and new growth beginning to push forth.....	Apr. 6	May 7
New upright growth $\frac{1}{2}$ inch to $\frac{3}{4}$ inch long.....	Apr. 10	May 14
Blossoms in "hook stage".....	May 12	June 14
Vines in full bloom.....	June 9	June 30
Blossoms falling and berries setting.....	June 30	July 30

Such local influencing conditions as depth of vines, depth of the underlying peat, or protection from the strong northwest wind which commonly blows during much of the early growing season will, of course, cause wider local variations than those here given. The limits of each phenological stage are even more variable than the height, it being not uncommon, for instance, to find blossoms on some vines as early as May 12 and on others, many not yet fully opened, by July 15. An early spring, too, would have the effect of somewhat advancing the dates given in this table and a late one would probably delay the early stages a little, but the later stages, such as blooming and setting of berries, would probably be delayed to a less extent.

INTRODUCTION OF THE BLACKHEAD FIREWORM INTO THE NORTHWEST.

Although the blackhead fireworm is found on the wild cranberry³ as far as 2 miles from any cultivated vines, the severest infestations in Washington and Oregon are on bogs planted originally with vines from Wisconsin, New Jersey, and Massachusetts. A study of the history of the cranberry industry on the Pacific coast and of the

³ Specimens growing wild in southwestern Washington were submitted to Dr. F. L. Pickett, of the Washington Agricultural Experiment Station and were determined by him as the common western cranberry, *Oryzococcus (oryzococcus) intermedius*, with the following note: "This is a little coarser than the small cranberry of the East, and bears slightly larger berries."

origin of the cuttings used furnishes convincing evidence that large numbers of the eggs of this pest were brought into this region on the leaves of cuttings from bogs in these three States. These cuttings, principally from Massachusetts bogs, were used extensively in planting a large number of bogs set out in Washington and Oregon between 1912 and 1915, which was about the time the blackhead fireworm became a pest of considerable importance in the regions from which these cuttings were imported.

After the newly planted bogs had made sufficient growth, it was the practice to mow them and use the cuttings thus obtained to plant other areas, as these cuttings could, of course, be obtained at less cost and in better condition than those from the East. So, helped in this way, the blackhead fireworm spread over practically the entire region. Once established on a bog it was a matter of only a few seasons until this pest had overrun nearly every part of it and caused considerable damage almost before the owner was aware of its presence.

DISTRIBUTION.

The blackhead fireworm is found on nearly every cranberry bog on the Pacific coast. It has long been a pest of the cranberry in New Jersey, Massachusetts, and Wisconsin, where it now causes as much damage as any other cranberry pest and often more. According to Fernald,⁴ it has also been found on the cranberry in New York and California.

FOOD PLANTS.

Numerous small larvæ resembling very closely in appearance those of *Rhopobota naevana* were found feeding on some common bog plants, such as "buck brush"⁵ and "sweet gale."⁶ None of these proved to be the blackhead fireworm; and, so far as known on the Pacific coast, *Rhopobota naevana* feeds only on the cranberry, both native⁷ and cultivated.⁸

DESTRUCTIVENESS.

The injury to the cranberry by the blackhead fireworm is caused by the feeding of the larvæ, or worms, on the buds, foliage, blossoms, and fruit throughout the growing season. It is very characteristic and quite unmistakable; there is no other pest of the cranberry on the Pacific coast the work of which is similar in all respects

⁴ Fernald, C. H. A Synonymical Catalogue of the Described Tortricidae of North America North of Mexico. In Trans. Amer. Ent. Soc., v. 10, p. 48. 1882.

⁵ Specimens of this plant were identified as *Spiraea douglasii* by Dr. F. L. Pickett, of the Washington Agricultural Experiment Station.

⁶ Also identified by Dr. Pickett as *Myrica gale*. "It belongs to the bayberry group."

⁷ *Oxyococcus (oxyococcus) intermedius*, the common western cranberry.

⁸ *Oxyococcus macrocarpus*, the common cultivated cranberry.

to that of the blackhead fireworm, nor has the cranberry there any other pest which annually destroys so much as this one.

The young larvæ start to feed on the newly growing tips shortly after they hatch, in the months of April and May, and continue their work throughout the growing season, attacking in greater or less severity the buds, blossoms, and later the berries, injuring the berries by boring into them and causing them to shrivel and dry and often to fall from the vines. The most noticeable feature of the attack of the fireworm during the middle or latter part of the summer is the burnt appearance of the vines which results from the work of this insect, suggesting the name fireworm. Since the terminals are most affected, few if any fruit buds are set when the vines are badly infested, and as a result nearly all the crops of the current season and of the following year are destroyed by the feeding of the larvæ during a single season. The vines, while never completely killed, are very much stunted and by the end of the summer are left stripped of the majority of the leaves. They are often brittle, and in the case of long-standing infestation are short and scrubby with numerous short and crooked branches as a result of being prevented from making a natural terminal growth. From this condition they do not usually return to their normal productiveness until good control work has been in force for several years.

NUMBER OF GENERATIONS.

By rearing the insect from the winter egg stage in an outdoor shelter it was found that it passes through two generations and sometimes a partial third. For example, the hatching of the winter eggs starts the first generation, and the resulting larvæ which change into pupæ and moths also belong to the first generation.

The eggs that these moths lay start the second generation. Contrary to the behavior of this pest in the East, only about four-fifths of these eggs hatched to form a second generation the same season in which they were deposited. The remaining one-fifth did not hatch until the following spring.

All the eggs deposited by the moths resulting from the second set of individuals are known as the eggs of the third generation. So far as is known, in eastern cranberry regions the eggs of this generation do not hatch until the following spring. On the Pacific coast, however, it was found that about one-third of the eggs of this generation hatched late in the summer, forming a third generation of larvæ. Because of adverse weather conditions toward the latter part of the season, none of these larvæ developed into pupæ and moths. This generation is therefore called a partial or incomplete generation.

DESCRIPTION OF STAGES AND HABITS.

THE EGG.

The egg of the blackhead fireworm is smooth, slightly elliptical, with the center partially raised and rounded. It measures approximately 0.65 millimeter wide, or about the size of the head of a very small pin. When first laid it has a slight opalescent sheen and a light lemon-yellow color which changes to a deeper yellow in about two weeks. The hatched egg is more inconspicuous, being transparent and appearing much like a small drop of albumin which has dried on the leaf. (Fig. 1.)

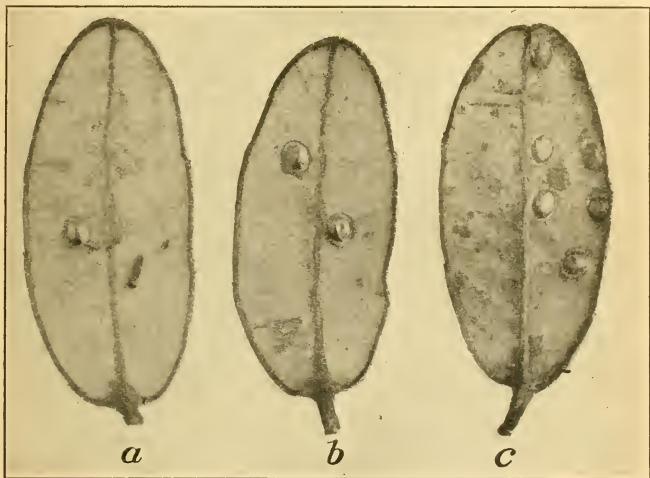


FIG. 1.—Eggs of the blackhead fireworm moth on the undersides of the cranberry leaves, enlarged 7.5 times: *a*, Winter eggs; *b*, eggs in the "black-spot" or first stage of development; *c*, hatched eggs.

HIBERNATION.

The eggs are laid by the parent moth singly or in groups on the underside of the cranberry leaves; rarely, a few eggs will be found deposited on the upper surface of the leaves. On the badly infested bogs as many as 10 or 12 eggs may be found on the underside of a single leaf. The majority of the wintering eggs are usually deposited on the leaves on the lower portions of the vines, the short, low uprights near the ground generally containing the greatest number of eggs. During picking season and the following winter, many of these leaves are dislodged from the vines, and it is not an uncommon thing to find them on the bog floor bearing numerous eggs. An infestation may easily be distributed from one part of a bog to

another by these leaves drifting from place to place over the bog in and on the water which sometimes collects during the winter time. Instances were noted in which numerous egg-bearing leaves had been washed into a corner of a bog, where they almost covered the vines. These eggs, being the first affected by rising temperatures, were the first to hatch in the spring, and the young larvæ had almost completely destroyed the surrounding uprights before eggs elsewhere in the bog had hatched.

INCUBATION AND HATCHING.

The first signs of incubation are noted as the black head and thoracic shield of the developing larva begin to show through the chorion or eggshell. As development progresses the young larva may be seen to move within the egg and finally, as it grows in vigor, to rupture the egg wall at a point over its mandibles and gradually escape by means of a wriggling sidewise motion through this slitlike opening, which is near the top of the upper surface of the egg. (Fig. 1, *b*, *c*.) It usually takes from about 3 to 5 minutes for the larva to free itself entirely from the eggshell.

FACTORS INFLUENCING HATCHING AND DEVELOPMENT.

(*a*) *Temperature*.—Temperature has the greatest influence on the fireworm eggs as well as on the other stages. This varies more than is generally supposed among different bogs, depending upon location.

(*b*) *Depth of vines*.—Another very important factor which tends to retard or hasten development of fireworm eggs is the depth of the vines in which they are deposited. A bog with thin vines will warm up more readily in the spring and maintain a higher temperature generally throughout the season than a bog with rather thick vines. Observations show, for instance, that on bogs with thin vines, hatching generally starts during the first warm days of spring (sometimes late in March or in early or mid-April), reaches its maximum early (say towards the latter part of April), and produces moths in maximum numbers in the middle or late part of June. On a thickly vined bog, in the same locality, however, and under similar conditions of temperature and moisture, hatching, while it may start about the same time as it does on the thinly vined bog, will be only desultory until the vines have warmed up considerably. Hatching in maximum numbers may not take place then until the middle or latter part of May. This in the absence of a winter flooding distributes hatching, on bogs with a medium or heavy growth of vines, over a considerable period.

(*c*) *Drainage*.—During the winter or rainy season more or less water usually accumulates on the majority of the cranberry bogs

on the Pacific coast. On those which are not quickly and easily drained this winter water remaining on the bog late in the spring causes the vines and the fireworm eggs to be rather slow in developing, with a consequent grouping of the hatching and development of the first generation of larvæ.

THE LARVA.

The newly-hatched larva of the blackhead fireworm (fig. 2, *a*) is about 0.1 mm., or a little over one-thirty-second of an inch in length; at first it has a pale yellow color which turns to a darker yellow with age, and has a relatively large dark brown or black head, accentuated by the thoracic shield, the first segment back of the head, which is nearly as dark as the head; hence the name "blackhead."

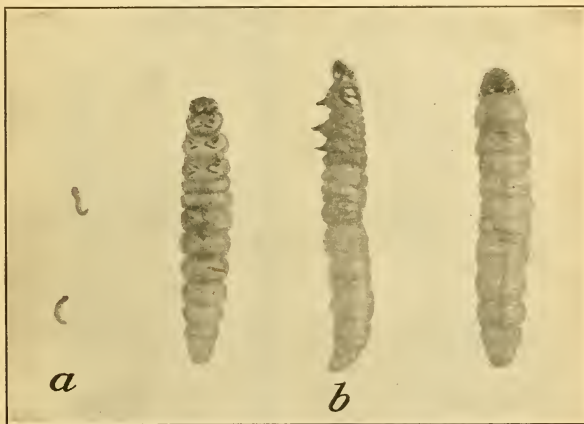


FIG. 2.—The blackhead fireworm: Views of the larva, enlarged 7.5 times: *a*, Newly hatched larvæ; *b*, dorsal, lateral, and ventral views of full-grown larvæ.

When fully grown (fig. 2, *b*) the larvæ measure about 6.5 mm., or about one-fourth inch in length, and are dark greenish yellow with a coat of darker olive green above. The head and thoracic shield are black. The larvæ are very active from the time they are about one-fifth to one-fourth grown and vigorously wriggle from their galleries when disturbed, falling to the ground and quickly concealing themselves among the trash and leaves beneath the vines by a characteristic sidewise and backward movement of the body. They are provided with three pairs of thoracic legs, four pairs of abdominal legs, and one pair of anal legs. Depending upon the weather and the time of the season, the blackhead fireworm spends from 10 to about 75 days in the larva state.

FEEDING HABITS.

A newly hatched larva begins feeding shortly after it leaves the egg, but may wander about for from 15 minutes to half an hour before taking any food. It usually starts feeding on the underside of the leaves, generally near the eggshell from which it has just emerged. At first it bites into the epidermis of the leaf, and, mixing the nibblings with the thread of silk which it spins continuously from several points beneath its lower lip, soon covers itself with a

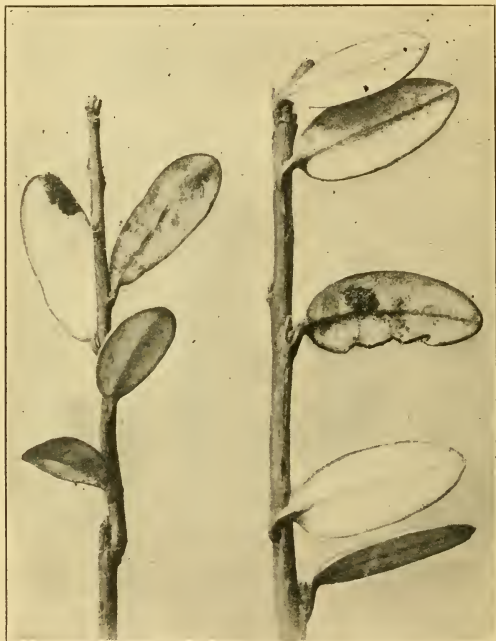


FIG. 3.—The blackhead fireworm: Characteristic work of the newly hatched larvæ on the underside of cranberry leaves.

greenish brown material which has the appearance of fine sawdust. For a time it continues to chew into the leaf, feeding principally between the upper and lower surfaces, acting in many respects like a leaf-miner. (See fig. 3.) This is particularly characteristic of the early-hatched larvæ of the first generation. The larvæ of this generation which hatch later, and usually those of later generations hatched in warmer weather after the new growth is well out, proceed almost directly to the tip, spending very little time as leaf-miners.

Depending upon the prevailing temperature and the condition of the weather at this time, the young larva in a somewhat dormant condition spends two weeks, more or less, in its burrow, feeding only when the weather is warm and favorable. If the weather is warm it will be quite active and may stay in its burrow only two or three days. On badly infested bogs it is a common thing to find the underside of the lower leaves on the vines badly chewed and full of burrows. The majority of instances of this type of injury are doubtless caused by the larva hatching early in the spring before the bogs have become sufficiently warm to permit active feeding, and also by those hatching late in the fall, as is often the case on account of the bogs being exposed to the weather the year round.

At the approach of warm weather, or after the young larva has grown larger and stronger, it leaves its burrow and proceeds toward the tip of the upright. Here, if the weather should turn cool, it starts to feed in the whorl of leaves about the terminal fruit bud and incloses itself in a loosely constructed web of frass and silk, either between two terminal leaves or between the bud and the adjoining leaf, where it awaits more favorable conditions which may cause the terminal bud to break and grow. As these conditions become intensified the larva proceeds to web up the unfolding leaves as it feeds on and skeletonizes them from within. From about the latter part of May or the beginning of June this injury is noticeable to the casual observer, many of the short, new uprights assuming a withered and bent-over appearance at the tip, similar to those shown in the accompanying illustration (fig. 4).

As the weather becomes warmer and the vine growth increases the fireworms, the majority of which at this time (about early June) may be nearly one-half to three-fourths of an inch long, feed rapidly on the leaves in their web galleries, gradually extending them or moving to an adjacent tip or upright as new food is needed. The vines gradually assume the characteristic dried, light yellow-brown appearance, and as feeding continues the bog begins to look as though a fire had swept over it, scorching the tips of the vines, which by midsummer are dry, reddish brown, and often nearly leafless; whence the name "fireworm."

On a vigorously growing bog the late-hatched larvæ of the first generation often feed upon the unfolding blossoms and newly formed berries, sometimes causing them to drop from the vines. In their feeding the young larvæ frequently burrow into the blossoms at a point near the base of the petals and feed on the floral organs within, or they may bore into the ovary directly from the outside. This feeding is first noticed about the time when the blossoms are in the "hook stage" or about the beginning of June on the early bogs. At this time a few very small larvæ usually may be seen eat-

ing into the blossoms or berries, as described above; later on, both large and small larvæ may attack the berries, eating into them where the berries touch one another or the leaves or an adjoining upright. (See fig. 5.)

The second generation of worms makes its appearance in considerable numbers the latter part of July. These larvæ not only feed upon the foliage, like those of the first generation, but they also web it up more, feed longer, and move from place to place much oftener than do the larvæ of the first generation. Especially on bogs



FIG. 4.—The blackhead fireworm. Early work of the larvæ in the tips: *a*, Entire new tip destroyed; *b*, showing how the tip leaves are webbed together; *c*, an uninjured upright.

making little new growth they may extend their feeding to the old foliage, including many of the old uprights in their webs. In addition, many of them may also feed extensively throughout the remainder of the season on berries of all sizes. It does not seem to make much difference whether the berries are webbed up or not; in fact, the majority of the berries attacked are not webbed up at all. (See fig. 5.) The injury done by the second generation of larvæ is, therefore, very striking. The third generation of worms is not very distinct from the second and not quite so numerous; but occurring

later in the season, when the vines are maturing, these larvæ feed principally on the berries, and therefore do more immediate damage to the crop if any remains on the vines.

The result of the work on all three generations is not only the destruction of the current season's crop or its material reduction but also the loss of a considerable proportion of the crop the following year, the setting of fruit buds being largely prevented by the attack of the larvæ on the terminals. It will thus be seen that the fireworm in one season can very materially reduce the cranberry crop of two seasons.



FIG. 5.—The blackhead fireworm: Injury of the larvæ to the berries. The large berry on the upright is uninjured.

PLACE OF PUPATION.

After the larvæ have reached their full growth they usually leave the webbed uprights and descend to the trash and leaves beneath the vines, where they inclose themselves between several old leaves in more or less loosely constructed cocoons, typical specimens of which are shown in figure 6. Sometimes, however, especially in the case of the larvæ of the first generation, some may spin themselves up within a thin cocoon in the tips of the uprights, as shown in figure 7. Very

often some larvæ, after feeding in a cluster of berries, will spin their cocoons and also pupate on the inside of one of them, or they may fasten their cocoons between the berries, mixing their silk with frass and any skeletonized leaves available. This is commonly true of the larvæ of the second generation. It is not very unusual, therefore, to find some berries with the empty pupa cases protruding from a hole in the side. The great majority of the larvæ of all generations, however, descend to the ground to pupate.

THE COCOON.

As previously referred to, the cocoon of the blackhead fireworm is composed of strands of silk which the larva fastens to any surrounding objects, as frass, leaves, or berries, and more or less loosely draws



FIG. 6.—The blackhead fireworm: Typical cocoons formed out of dead cranberry leaves beneath the vines. The ones in the top row have been opened to show the interior; those in the lower row show the empty pupa cases protruding. All slightly enlarged.

about itself preparatory to pupation. The interior of the cocoon is shown in figures 6, 7, and 8. It is in cocoons similar to these that the larvæ pass through a resting period followed by a final molting of the larval skin. This resting and molting, during which the pupa or chrysalis is formed, is called pupation.

THE PUPA.

The pupa or chrysalis of the fireworm is about 5.5 mm. or a little less than one-fourth inch long by 1.5 mm. or about one-sixteenth inch wide, and of a light amber yellow color immediately after casting the larval skin. This color soon changes to a deeper amber brown, and in pupæ about to change to adults the color is a very deep amber approaching almost black. The pupæ are not usually encountered without a rather close examination of the leaves and trash beneath

the vines in which, as already mentioned, most of the individuals of all generations pupate. (See fig. 8.)

The pupæ wriggle considerably when first picked up, moving the end of the abdomen in a circular motion, but they have no power of locomotion such as the larvæ have. Just before the moth is ready to emerge, and in order that it may do so without hindrance, the pupa,



FIG. 7.—The blackhead fireworm: Pupa in cocoon spun in a tip of a cranberry upright. Enlarged 6 times.

by means of this wriggling motion and with the aid of a number of small backwardly directed spines arranged in double rows around the back of each segment of the abdomen, forces itself out through the end of its loosely spun cocoon until the thorax and the tips of the wing pads are free of the edge of the cocoon. (See last specimen at right in lower row of fig. 6.)

The duration of the pupa stage varies from 10 to about 65 days, depending upon the weather and the time of the season.

THE ADULT.

The adults, or moths, of the blackhead fireworm are conspicuous because of their habits of flight; when disturbed they often rise in very large numbers. Upon close examination they are found to be small in size, measuring in length from the tip of the head to the tip of the wing on the average about 6 or 7 mm., a little over one-fourth of an inch, or about the same length as the mature larvæ. With the wings spread they measure about 10 mm. across, or a little over three-eighths of an inch.

The moths (fig. 9) differ somewhat in color, seeming to vary especially according to age. The first pair of wings of freshly emerged



FIG. 8.—The blackhead fireworm: View of pupa and interior of cocoon. Enlarged about 7.5 times.

and unrubbed specimens have a ground color above of deep silver gray, with irregular markings of brown, which often give them a golden-brown sheen. Characteristic markings of a single row of short alternating brown and silver-gray bars running diagonally to the front margin are found on the first or upper pair of wings. The second or lower pair of wings of the female are without characteristic markings; those of the male have an irregular dark spot on the underside near the front margin. The second or lower pair of wings of both male and female have a fringe of long, bristlelike scales extending from near the tip along the back margin to the body. The abdomen is medium and slender, depending on the sex, female specimens having a somewhat broader and shorter abdomen than the males. The abdomen and the legs are covered with dark silver-gray scales, which

often have a light golden-brown sheen. The antennæ are about one-half the length of the body and more or less bristlelike.

The adults live from 3 to 33 days after they emerge, and during this time eat little or nothing, except, perhaps, a little nectar from the blossoms, or water in the form of dew or rain.

HABITS OF FLIGHT.

After the moth emerges from the pupal case it rests for a short time, during which the wings are spread and dried. It then starts to fly and moves rather swiftly in a short, jerky, darting motion, making usually only short flights from place to place over the vines. Particularly on heavily infested bogs the moths are very conspicuous for their habits of flight. They will often be seen to rise in large numbers when disturbed, as by spraying or by a person walking through the vines on a warm afternoon, suggesting to some the appearance of a cloud.

PERIODS OF ACTIVITY.

A few moths may generally be seen flying from tip to tip almost every hour of the day from the time of their first appearance in June until late in September and October, but the time of day they are most active is from about 3 o'clock in the afternoon until after dusk. During this period, especially if the weather is warm, they may be seen to rise in the air for a few feet, making their characteristic short, jerky flights.

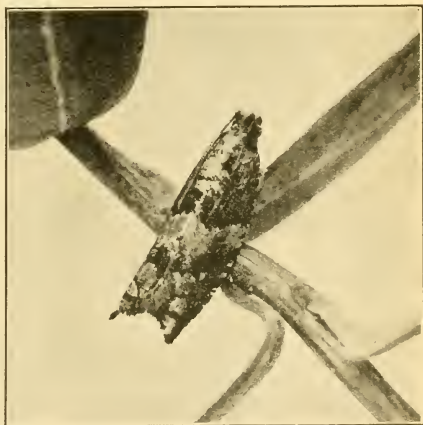


FIG. 9.—The adult or moth at rest on a cranberry upright. Enlarged about 6 times.

MIGRATION.

It is in the moth stage principally that the blackhead fireworm spreads itself over the bog or invades an adjoining one. The moth, however, flying only short distances, would not naturally migrate more than several yards from its original region of activity; but, helped by the wind, it is possible for it to be carried as far as several

hundred feet in one flight, and it is thus that bogs neighboring badly infested ones, especially to the leeward, may become badly infested in a few seasons.

Other ways in which the fireworm is disseminated over a bog have been mentioned, namely, in the egg state, on leaves floating over the bog in the winter water (p. 7-8), and also on cuttings (p. 4-5).

PROPORTION OF SEXES.

In 1918, of 158 moths of the first generation emerging in the insectary, 81, or 51 per cent, were males, and 77, or 49 per cent, were females; of 59 moths of the second generation, 24, or 41 per cent, were males, and 35, or 59 per cent, were females. In 1919, of 101 moths of the first generation emerging in the insectary 53, or about 52 per cent, were males, and 48, or about 48 per cent, were females; of 52 moths of the second generation 24, or 46 per cent, were males, and 28, or 54 per cent, were females. This shows a slight predominance of males over females in the first generation and the opposite in the second generation.

COPULATION.

Copulation usually occurs shortly after emergence. Of those pairs observed in the rearing shelter, one was found copulating the same day it emerged, two the day after emergence, and one pair did not copulate until 7 days after emergence. The same pair was never seen to copulate more than once.

The period of copulation varies in length, the minimum period observed being 1 hour and 26 minutes and the maximum 26 hours and 55 minutes. The male of one pair observed was noted dead and still attached to the female 3 days after copulation was first observed.

OVIPOSITION.

Egg-laying commences shortly after copulation, usually within a few days. During oviposition the female rather quickly pushes the egg out through the tip of the abdomen, which she holds very close to the underside of the leaf. Here the egg, a soft, plastic drop, settles over the surface and soon assumes its ordinary flat, oval shape. The outermost covering, which is rather moist when the egg is first laid, dries and cements the egg to the leaf and gives it its appearance of being glued on. (See fig. 1, *a*.)

TIME OF DAY WHEN OVIPOSITION OCCURS.

Eggs may be laid at almost any hour of the day and evening when the weather is warm and fair. However, in order to determine the time of day when the moths were depositing eggs in largest numbers,

32 males and 42 females of the first generation were collected from a cranberry bog on July 15, 1918, and immediately confined as follows in three battery jars 9 inches high by 5 inches wide: Jar No. 1 contained 12 males and 12 females; jar No. 2, 10 males and 12 females; jar No. 3, 10 males and 18 females. Each jar was provided with a few inches of slightly moist sand on the bottom, an abundance of clean cranberry uprights, and a sponge moistened with a weak solution of sugar and water for food and moisture,

Every 3 hours from 2 a. m. to 9 p. m. daily until July 20 the uprights in each jar were replaced with fresh ones and the eggs on them and on the side of the jar counted and recorded. The sponge was also moistened daily.

The number of eggs found deposited at each examination is summarized in Table 2. As will be noted therein, eggs were laid during every period between examinations, but the largest number of eggs was deposited between 3 p. m. and 9 p. m., 663, or 39.6 per cent of the total, being deposited between 3 and 6 p. m., and 650, or 38.8 per cent, between 6 and 9 p. m. The smallest numbers were deposited in the 12-hour period between 9 p. m. and 9 a. m. It will be noted further that the time of day during which eggs were deposited in largest numbers is also the period of greatest activity on the bog.

TABLE 2.—*Number of eggs of blackhead fireworm moth deposited every 3 hours from 6 a. m. to 9 p. m. by moths of the first generation confined in battery jars; Seaview, Wash., July 15 to 20, 1918.*

Period of deposition.	Number of eggs deposited.	Per cent of total deposited.	Period of deposition.	Number of eggs deposited.	Per cent of total deposited.
9 p. m. to 6 a. m.....	78	4.6	3 p. m. to 6 p. m.....	663	39.6
6 a. m. to 9 a. m.....	8	.5	6 p. m. to 9 p. m.....	650	38.8
9 a. m. to 12 noon.....	67	4.0			
12 noon to 3 p. m.....	209	12.5	Total.....	1,675	100.0

The number of eggs found deposited at each examination is shown in graphic form in figure 10, together with a curve showing the hourly temperature during the period of the experiment. Attention is here drawn to the influence of the temperature on egg-laying. It will be noted that the largest number was deposited between 3 and 6 p. m. on July 16, a few hours after the highest temperature, namely, 75° F., was recorded.

SEASONAL HISTORY.

It was noted that larvæ of the first generation appeared in greatest abundance on the bogs about the latter part of May, the pupæ toward the middle of June, and the moths about the first or second week in July.

cocoon in the lower row of specimens in figure 11. The specimens in the top row have been dissected from the loosely constructed cocoons and show the fungous disease growing on the pupæ.

While this disease certainly causes the death of a large number of pupæ on bogs where it is prevalent, not too much reliance should be placed on it in the control of the fireworm, since the greatest part of the damage by the fireworm is done to the vines before the time when the fungous disease is growing rapidly. The weather also may or may not be favorable to its rapid growth, and hence its killing power and spread are likely to vary considerably from one season to another.

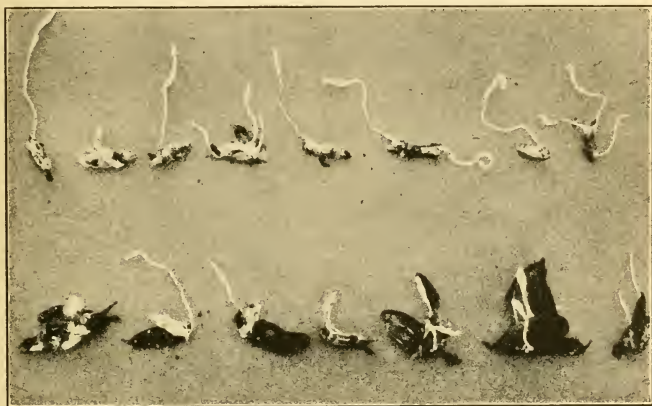


FIG. 11.—Fungous disease, a species of *Spicaria*, growing from the blackhead fireworm pupæ in their cocoons. Slightly enlarged.

PREDACIOUS ENEMIES.

SPIDERS.

On the cranberry bogs of the Pacific coast spiders of various kinds are found in very large numbers and doubtless devour many fireworm larvæ and moths.

INSECTS.

A large number of "ladybugs" are also seen on cranberry bogs, and their presence there sometimes causes alarm to a grower who is not familiar with their habits. One species, the California red ladybird beetle,¹⁰ is very common, and both larvæ and beetles can be seen actively walking over the tips of the cranberry uprights any

¹⁰ Specimens determined by Mr. E. A. Schwarz, of the Bureau of Entomology, as *Coccinella californica* Mann.

time throughout the summer. The ladybird beetles, with few exceptions, are beneficial insects; the adults of this species have been observed to feed readily on the larvæ of the blackhead fireworm in captivity, and in the field doubtless consume large numbers of this insect.

CONTROL EXPERIMENTS.

Since most of the cranberry bogs on the Pacific coast can not be provided with a sufficient supply of water for use in control work, insect pests on these bogs should be combated largely by the application of insecticides in the form of a liquid spray. This method seems especially desirable against the fireworm after a study of its habits and methods of feeding. It may also be necessary to do more or less spraying for certain fungous diseases at various times throughout the season, and some of the dates for these applications may correspond to a great extent with the time of application in the control of the fireworm. The grower, therefore, can combine the materials used for the control of the fireworm with those necessary for fungous diseases whenever the times for these two applications coincide, and thus save the expense of separate applications.

All the control experiments against the blackhead fireworm were arranged, therefore, so as to include tests under actual bog conditions of several methods of spraying the eggs, larvæ, and adults with a number of promising insecticides, both with and without spreaders, at various times throughout the season. These sprays were applied by the types of nozzles shown in figures 12, 13, and 14, all the tests being so planned as to shed some light on questions concerning the number of applications, the best materials to be used, the amount of spray material which should be used per acre, and the most effective manner of applying it.

MISCELLANEOUS SPRAYING EXPERIMENTS.

In Table 3 is given an outline and the results of the miscellaneous spraying experiments conducted on Howe vines on the Portland-Seaview Cranberry Co. bog at Seaview, Wash., in 1919. Very similar experiments were performed on this bog in 1918, but the severe infestations previous to that season had so reduced the bearing power of the vines that few blossoms were set in 1918, and the results therefore were not wholly dependable. They showed, however, a decided increase in control by the use of insecticides combined with spreaders, such as soap or glue, as compared with the same insecticides applied without the addition of these wetting agents. They also suggested that a solution of 40 per cent nicotine sulphate, used at the rate of 1 part to 1,000 parts of water, with the addition of fish-oil soap at the rate of 2 pounds to 50 gallons and applied at the rate of about 300

gallons per acre, might be just as effective as the same kind of a solution in which the nicotine was used at the rate of 1 part to 800 parts of water and applied at the rate of about 200 to 250 gallons per acre.

The miscellaneous spraying experiments conducted on this bog in 1919 were therefore planned in the light of the results of the previous season.

TIME AND NUMBER OF APPLICATIONS.

The odd-numbered plats, I to XV inclusive, received 3 applications on the dates shown in Table 3. The first application (May 13 and 14) was made to catch the largest possible number of small larvæ in and near the tips of the uprights before they had a chance to web up the new unfolding leaves. The new growth at this time was approximately three-fourths of an inch long. The second application, June 12, was made to kill the next lot of larvæ hatching after the first application and came about the time when the majority of the blossoms were in the "hook stage." In order to catch the late-hatching larvæ the third spraying was made July 1 and 2 as the vines were approaching full bloom. The even-numbered plats, from II to XVI inclusive, and plat XVII, received in addition to these applications just described one more application (July 16 and 17) about the time the moths were flying on this bog in greatest abundance. The purpose of this fourth application was to kill these moths and also any larvæ which had moved into the tips at this time.

While the frosts of May 4, 5, and 6 somewhat reduced the crop on nearly all the plats, the comparative results, as obtained by the examination of the berries from 3 circular areas of about 100 square inches, each picked at random over each of the plats, strengthen the observations made of these plats at various times throughout the season.

TABLE 3.—Outline of miscellaneous spraying experiments in the control of the blackhead fireworm on the Portland-Seaview Cranberry Co. bog at Seaview, Wash., 1919.

Plat No.	Spray materials, dosage, etc.	Number of gallons used calculated per acre per application.					Total number of berries examined.	Total number of berries free from injury.	Gain over check.
		May 13 and 14.	June 12.	July 1 and 2.	July 16 and 17.	Average per application.			
I.....	40 per cent nicotine sulphate, 1-1,000+fish-oil soap, 2-50.....	380	300	320	.....	333	388	<i>Per cent.</i> 92.52	<i>Per cent.</i> 15.50
II.....	40 per cent nicotine sulphate, 1-1,000+fish-oil soap, 2-50.....	380	300	320	480	370	402	95.52	18.50
III....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50.....	330	280	280	.....	297	735	93.74	16.72
IV.....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50.....	330	280	280	480	342	737	97.42	20.40

TABLE 3.—Outline of miscellaneous spraying experiments, etc.—Continued.

Plat No.	Spray materials, dosage, etc.	Number of gallons used calculated per acre per application.					Total number of berries examined.	Total number of berries free from injury.	Gain over check.
		May 13 and 14.	June 12.	July 1 and 2.	July 16 and 17.	Average per application.			
V.....	40 per cent nicotine sulphate, 1-600 + fish-oil soap, 2-50.....	295	270	270	.....	278	820	<i>Per cent.</i> 91.21	<i>Per cent.</i> 14.19
VI.....	40 per cent nicotine sulphate, 1-600 + fish-oil soap, 2-50.....	295	270	270	500	333	485	94.22	17.20
VII...	Powdered arsenate of lead, 2½-50 + fish-oil soap, 2-50.....	340	300	260	.....	300	401	83.04	6.02
VIII..	Powdered arsenate of lead, 2½-50 + fish-oil soap, 2-50.....	340	300	260	450	337	172	76.16	.96
IX....	Nicotine oleate, 1-300.....	295	270	270	.....	278	433	91.45	14.43
X.....	Nicotine oleate, 1-300.....	295	270	270	320	289	862	91.99	14.97
XI.....	40 per cent nicotine sulphate, 1-800 + glue, 1-200.	290	280	310	.....	293	703	83.64	6.62
XII...	40 per cent nicotine sulphate, 1-800 + glue, 1-200.	290	280	310	620	375	600	86.16	9.14
XIII..	Nicotine oleate, 1-400.....	300	320	350	.....	323	1,012	92.29	15.27
XIV..	Nicotine oleate, 1-400.....	300	320	350	660	407	1,061	91.42	14.40
XV...	Nicotine oleate, 1-500.....	330	380	320	.....	343	763	87.64	10.62
XVI...	Nicotine oleate, 1-500.....	330	380	320	600	407	827	92.38	15.36
XVII.	"Phenol compound" No. 1, 1-500.....	420	560	320	560	460	628	73.56	3.46
XVIII	Check, untreated.....	.....	.....	.....	.....	.....	74	77.02	.....

NOTE.—Mist nozzles as shown in figure 13 used for all applications, with hand barrel spray pump giving pressure of 50 to 100 pounds.

NICOTINE SULPHATE.

The conclusions drawn by Scammell¹¹ regarding the effectiveness and safety of 40 per cent nicotine sulphate in the control of the blackhead fireworm were borne out in the work on the Pacific coast. Of the various strengths used, 1 part to 800 parts of water with 2 pounds of fish-oil soap to each 50 gallons of solution, applied 4 times, seemed to give the highest percentage of cranberries free from fireworm injury; it will be noted in Table 3, however, that 4 applications of this material, used 1 to 1,000, gave nearly as great a gain over the check. The fact that it gave a higher percentage of clean fruit than 1 to 600 was probably due to the fact that there was a larger setting of fruit on this plat and perhaps a somewhat lighter infestation than on the one treated with the solution of the strength of 1 to 600.

NICOTINE OLEATE.

Nicotine oleate was made by stirring together the proportions of a 40 per cent solution of free nicotine and oleic acid according to the directions given by Moore¹² as follows:

¹¹ Scammell, H. B. A New Method of Controlling the Blackhead Fireworm. In Proc. 47th Ann. Conv. Amer. Cranberry Growers' Assn. (Aug. 26, 1916), p. 8-12; Cranberry Insect Problems and Suggestions for Solving Them, U. S. Dept. Agr., Farmers' Bul. 860, p. 4-9, 1917.

¹² Moore, William. A Promising New Contact Insecticide. In Journ. Econ. Ent., v. 11, no. 3, p. 341-342, 1918.

Two and one-half parts of a 40 per cent nicotine solution unites with $1\frac{3}{4}$ parts of commercial oleic acid or red oil. Four and one-fourth parts of this soap will then contain 1 part of nicotine or will equal $2\frac{1}{2}$ parts of the 40 per cent nicotine solution.

It will thus be seen that nicotine oleate is a *nicotine soap* made from a fatty acid and nicotine; as such it has the spreading properties of a soap and in addition it is a contact insecticide which can generally be used in place of the ordinary 40 per cent nicotine sulphate and soap solution for cranberry spraying. It could not be mixed, however, with *hard water* or combined with Bordeaux mixture or any other alkaline solutions; and since it takes $4\frac{1}{4}$ parts of the nicotine oleate to equal in nicotine content $2\frac{1}{2}$ parts of the 40 per cent nicotine solution, *about twice as much nicotine oleate as 40 per cent nicotine sulphate* had to be used to equal one part of the latter.

A spray material of this character, which has combined in it both soap and nicotine, would greatly facilitate the control of the fireworm, if not materially reduce the cost, wherever its use is practicable. Solutions of the strengths used seemed to spread equally well over the cranberry foliage. As shown in Table 3, it was used at the rate of 1 part to 300 parts of water, 1 to 400, and 1 to 500, about equal, respectively, to 1 to 600, 1 to 800, and 1 to 1,000 of the 40 per cent nicotine sulphate formulas. Both three and four applications were made of each strength. The largest percentage of fruit free from fireworm injury seemed to be obtained where nicotine oleate was used at the rate of 1 to 500 and applied four times. There is very little difference between the results of this plat (plat XVI) and those secured on plat XIII where nicotine oleate 1 to 400 was applied three times. This is partly explained by the fact that the fireworm infestation was more thinly scattered over the former plat than over the latter. The results where nicotine oleate was used at the rate of 1 to 300, while apparently very satisfactory, are not so good, considering all factors, as where it was used at the rate of 1 to 400.

ARSENATE OF LEAD.

As in 1918, arsenate of lead proved to be of little or no value in the control of the fireworm, the foliage being badly eaten and nearly all the berries destroyed by the worms, even where four applications were made with the addition of soap.

WETTING AGENTS OR "SPREADERS."

That the presence in the spray liquid of some material like soap, which will make it wet or spread over the smooth, waxy foliage of the cranberry, seems to make considerable difference in the control

results obtained was plainly shown by the preliminary experiments of 1918 previously referred to. In 1919, therefore, a comparison of the kinds of spreaders was made and in these tests glue, 1 pound to 200 gallons, and nicotine oleate at the strengths mentioned above were checked against fish-oil soap, 2 pounds to 50 gallons. As will be observed in Table 3, the use of glue gave the poorest control of the three groups of plats III and IV, XI and XII, and XIII and XIV, in all of which the strength of the nicotine was approximately the same; nicotine oleate was next; and fish-oil soap, 2 to 50, gave the best results.

Observations made immediately after these spreaders were applied showed that glue spread the solution fairly well over the old foliage, but failed to carry it into the small, new leaves at the tip, the region of greatest activity of the young larvæ; nicotine oleate spread very satisfactorily over both old and new foliage, but did not seem to go as far into the unfolding buds and leaves as did the solution containing fish-oil soap, which, moreover, might be one reason for the superior control secured where fish-oil soap was used as a spreader.

It was observed that fish-oil soap used at this strength would often carry the solution containing it into the very center of the group of small unfolding leaves at the tip of the upright and enable the solution to find its way into the loose web of any small larvæ which might be working therein.

"PHENOL COMPOUND No. 1."

A proprietary compound used primarily as a disinfectant and containing a large amount of crude carbolic acid was tested against the fireworm. This material mixes in all proportions with water, making a milky white solution which gives off a strong, characteristic carbolic-acid odor. It was used at the rate of 1 part to 500 parts of water and sprayed directly into the tips of the vines, as on the other plats. As will be noted in Table 3, little or no control was secured.

DEMONSTRATION SPRAYING EXPERIMENTS.

The results of a series of demonstration spraying experiments, conducted on the bogs belonging to H. M. Williams & Sons, at Ilwaco Junction, Wash., in 1919, are presented in Table 4. The material found most effective in previous tests, namely, 40 per cent nicotine sulphate, 1 to 800, with soap 2 to 50, was used in all these experiments.

TABLE 4.—Outline of spraying experiments in the control of the blackhead fireworm on the H. M. Williams & Son's bog at Ilwaco Junction, Wash., 1919.

Plat No.	Spray materials, dosage, nozzle, and variety of cranberry.	Number gallons used per acre per application.					Total number of berries examined.	Berries free from fireworm injury.		Gain over check.	Yield per acre.	Gain in yield over check.
		First, May 2-6.	Second, May 20-21.	Third, June 13-17.	Fourth, July 9-10.	Average per application.		Unfertilized and immature.	Total number free.			
A....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, mist nozzle, Howe variety.	378	378	418	.....	391	1,071	<i>Per ct.</i> 54.44	<i>Per ct.</i> 89.35	<i>Per ct.</i> 30.27	<i>Bush.</i> 31.32	<i>Bush.</i> 18.52
B....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, Bordeaux nozzle, Howe variety.	457	666	444	.....	522	1,355	58.67	89.74	30.66	46.98	34.18
C.....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, "spray gun," Howe variety.	300	389	257	417	341	1,238	62.52	93.05	38.10	56.99	40.88
D.....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, "spray gun," Howe variety.	300	389	257	.....	315	1,499	54.30	84.25	29.30	75.06	58.95
E.....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, "spray gun," McFarlin variety.	300	327	267	268	290	1,075	45.30	87.72	46.16	176.88	161.85
F....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, "spray gun," McFarlin variety.	300	327	267	.....	298	1,162	41.22	77.45	35.89	124.65	109.62
G....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, Bordeaux nozzle, McFarlin variety.	563	697	884	643	697	1,345	69.00	91.97	50.41	168.84	153.81
H....	40 per cent nicotine sulphate, 1-800 + fish-oil soap, 2-50, mist nozzle, McFarlin variety.	499	388	499	554	485	2,343	56.50	93.81	52.25	364.26	349.23
1.....	Check on lee of plats A and B, Howe variety, untreated (for check on plats A and B).	.....	.....	.....	.....	.....	479	44.88	59.08	.....	12.80	.....
2.....	Check on lee of plats C and D, Howe variety, untreated (for check on plats C and D).	.....	.....	.....	.....	.....	626	43.93	54.95	.....	16.11	.....
3.....	Check on lee of plats F and H, McFarlin variety, untreated (for check on plats E, F, G, H).	.....	.....	.....	.....	.....	474	33.55	41.56	.....	15.03	.....

Here an effort was made to test the three types of nozzles, namely, the Bordeaux, the mist type, and the spray gun, on as large a scale as possible, and to approach commercial spraying conditions. The plats selected ranged in approximate size from one-fourth to one-half acre and included the Howe and McFarlin varieties. These were previously badly infested with the fireworm and yielded few or no berries in 1918. Figures 12, 13, and 14 show these three types in actual use, and Table 4 shows the number of gallons per acre used in spraying with each type of nozzle, with a pressure of about 250 pounds at the tank. A stationary power outfit was used for all the applications, pipes being used to convey the spray liquid from the pump to the plats.

Plats A and B constituted one section, containing about an acre of vines, C and D another to the south, and E, F, G, and H a third to the east of C and D. Since the infestation of these three sections varied somewhat it was thought advisable to have a check plat measuring 1 by 2 rods for each section. As noted in Table 4, they were placed to leeward of the plats of which they acted as checks to prevent the unnatural spread of moths over the plats. These were numbered 1, 2, and 3, respectively.

The percentages of berries free from fireworm injury, as shown in Table 4, were obtained from an examination of the berries picked at harvest time from five circular areas of approximately 100 square inches each, selected at random on each sprayed plat. Berries were examined from three such areas on each of the check plats.

The yield of each plat was obtained by measuring its entire crop as picked at harvest time. Plats A, B, C, and D were picked with a scoop, and plats E, F, G, and H were picked by hand. The first four plats included vines of the Howe variety and the last four, vines of the McFarlin variety, all of which had reached the age of normal bearing.

TIME AND NUMBER OF APPLICATIONS.

The first three applications were made at practically the same time for all plats, since the growth of the two varieties on these plats was very much the same. The first application was made on May 2 to 6, about the time when the largest number of buds were pushing forth but had not exceeded a growth of approximately three-fourths of an inch. This was the time when the young larvæ were appearing in very large numbers but before many of them had got beyond reach of the spray.

The second application was made May 20 and 21, when many blossoms were in the hook stage, and was timed so as to catch the next lot of larvæ before they could conceal themselves in the new growth.

The third came June 13 to 17, when the vines were nearly in full bloom. It was designed to kill any late-hatching larvæ of the first generation which might have been injuring the blossoms and newly forming berries.

Plats C, E, G, and H received a fourth application on July 9 and 10 at about the time many berries were already set. This application was intended to kill any very late-hatching larvæ and the moths which appeared on the bogs in largest numbers about this time.

THE BORDEAUX NOZZLE.

The Bordeaux nozzle is modeled so as to deliver a forceful, driving spray in the shape of a fan. The nozzle is so arranged that the intensity of the fan-shaped spray can be regulated as desired. In



FIG. 12.—Bordeaux nozzle equipment used in spraying experimental plats: *a*, Nozzles held to show delivery of fan-shaped spray on a horizontal plane; *b*, nozzles held in proper position for delivering spray to vines.

spraying plats B and G with this type of nozzle, an effort was made to hit on a nearly horizontal plane the underside of all the leaves, as well as to penetrate the vines and wet thoroughly with the spray solution all parts of the uprights, including the tips, by directing a forceful stream of spray, as shown in figure 12 *b*. The main idea was to wet the eggs and also to catch the young larvæ in their burrows on the undersides of the lower leaves, as well as to wet any larvæ in the tips at the time.

As will be observed in Table 4, three applications with this nozzle on Howe vines in plat B at an average rate of 522 gallons per acre resulted in a gain in yield of 34.18 bushels per acre over the untreated plat; 89.74 per cent of the berries examined from this plat were free from injury by the fireworm. On the McFarlin vines in plat G four applications at an average rate of 697 gallons per acre, with this type of nozzle, produced a gain of 153.81 bushels per acre over the check and 91.97 per cent of the sample berries were free from fireworm injury. The small yields of plats A and B were due largely to the fact that since the vines in this section had been very badly infested the previous season, they produced very scanty bloom, and they also appeared to suffer more from frost on May 4, 5, and 6 than the other plats.

THE MIST NOZZLE.

The mist nozzle used was of the eddy-chamber or whirlpool-disk type, somewhat larger than the Vermorel and without the center-cleaning punch of the latter. It is so constructed internally as to throw a medium fine mist in the form of a hollow cone of spray which, depending upon the pressure of the liquid, measures from 12 to 18 inches in diameter about a foot from the nozzle. The outfit, as shown in figure 13, was made from galvanized iron pipe one-fourth to three-eighths of an inch in diameter on which four nozzles were placed 11 inches apart and the whole attached to the end of an ordinary 8 or 10 foot bamboo spray pole. The first nozzle on the end was set close to the pipe and each succeeding one was set 1 inch farther away than the preceding so that all would be the same distance from the vines when the rod was held by the operator in proper position for spraying.

The applications with this type of nozzle on plats A and H were made with the primary idea of filling the terminal whorl of old leaves and the new unfolding leaves at the tip of the upright with the nicotine sulphate and soap solution. As will be seen in figure 13, this spray was delivered on a more or less vertical plane, and no special effort was made to hit the underside of the leaves, entire dependence being placed on a thorough soaking of the tips of the uprights, which was quickly and easily done with this type of nozzle.

On the Howe vines in plat A, three applications, at an average rate of 391 gallons per acre, with the mist nozzle produced a gain in yield of 18.52 bushels per acre over the check; 89.35 per cent of the berries picked from sample areas were free from fireworm injury. On the other hand, the same type of nozzle used on McFarlin vines in plat II, with four applications at the rate of 485 gallons per acre, produced a gain over the untreated vines in this section of 349.23 bushels per acre, 93.81 per cent of the berries examined being free from fireworm injury.



FIG. 13.—Mist nozzle equipment used in spraying experimental plats.

THE SPRAY GUN.

The spray gun (fig. 14) comprises usually a very large nozzle of the eddy-chamber type attached to a piece of tubing of varying length, fitted with a device for regulating at will the size and volume of the spray delivered through the nozzle. It is of larger capacity than the ordinary mist nozzle of the eddy-chamber type and is intended to be used only on power outfits where the pressure can be maintained at 200 pounds or over. In these experiments this type of nozzle was used at full-capacity opening with a medium-sized disk and threw a stream of spray about 15 to 20 feet long, which broke up into a medium fine mist before it reached the vines.

In the use of the spray gun on plats C, D, E, and F an effort was made to fill the tips of the uprights with the spray liquid and also to hit the undersides of the leaves by holding the nozzle close enough to the vines so that the liquid would be delivered on a nearly horizontal

plane. In this position the uprights would be bent over slightly and the tips as well as some of the lower leaves given a thorough wetting.

As seen in Table 4, three applications with this type of nozzle on the Howe variety (plat D) resulted in an increase of 58.95 bushels per acre over check, and 84.25 per cent of the berries examined were free from fireworm injury. Four applications on the same variety on the adjoining plat (plat C) resulted in a gain in yield of only 40.88 bushels over the check, doubtless because of the thin setting of blossoms on this plat, but 93.05 per cent of the fruit examined from the sample areas was free from fireworm injury.



FIG. 14.—Spray-gun used in spraying experimental plats. Shows size of stream of spray used, with medium-sized disk at full capacity.

On the McFarlin variety (plat F) three applications gave a gain of 109.62 bushels per acre over the untreated vines, 77.45 per cent of the examined fruit being free from fireworm injury. Four applications (plat E) gave better results, a gain of 161.85 bushels over the untreated vines, 87.72 per cent of the examined fruit being sound.

THE THREE TYPES OF NOZZLES COMPARED AS TO ECONOMY OF TIME AND MATERIAL.

With the Bordeaux outfit (fig. 12) it took about $1\frac{1}{2}$ hours to spray an acre, an average of 609 gallons being necessary for a thorough application. It was necessary to walk about 24 times across the acre, which was in the form of a square. With the mist outfit (fig. 13), it took about 1 hour to spray an acre, 438 being the average

number of gallons used for a thorough application. Approximately 12 trips were necessary across an acre with this outfit. In point of time and material the spray gun was the most economical, requiring only 35 or 40 minutes to spray an acre, with an average of 375 gallons for an application. It was necessary to make only 6 to 8 trips with one spray gun across an acre.

EFFECT OF THE NICOTINE-SULPHATE-AND-SOAP SOLUTION ON THE CRANBERRY PLANT.

Although 40 per cent nicotine sulphate in the proportion of 1 part to 800 parts of water with fish-oil soap at the rate of 2 pounds to each 50 gallons of solution was applied to the vines when they were almost in full bloom, no decided decrease in the setting and maturity of the berries seemed to occur on those plats on which the spray was not applied forcefully or on a nearly horizontal plane. It will be noted, however, in Table 4 that the percentage of unfertilized and immature berries, i. e., the very small, dried, and undeveloped ones, but which were free from fireworm injury, was slightly, and in some cases considerably, increased in all the sprayed plats except F as compared with the respective untreated ones, the three plats with the highest percentage of berries of this kind being plats B, C, and G. Some explanation of this may possibly be found in the fact that in two of these plats, namely, B and G, the spray was applied forcefully with the Bordeaux nozzle on a nearly horizontal plane, which probably could have seriously affected the fertility of the blossoms, as in some cases they were almost blown from the uprights. Plat C received four rather forceful applications with the spray gun, and this also may in a measure account for the high percentage of unfertilized berries picked from this plat.

It is generally recognized among cranberry growers and others familiar with cranberry culture that the presence of a large amount of wet weather during the blooming period sometimes results in a small crop of berries. Whether or not the wet weather causes a decreased crop by preventing the ordinary pollenization by insects or by destroying the fertility of some blossoms still seems to be a matter of conjecture. Since all the plats were affected by the same set of natural conditions, however, it would seem logical to suppose that the spraying of the vines while the blossoms were open with a type of nozzle which delivered a forceful spray on a more or less horizontal plane, and which thus thoroughly wet the floral organs, might have caused the comparatively small crop on the plats thus treated, by the sterilization and mechanical destruction of the blossoms.

On the other hand, a certain rather beneficial effect in addition to the control of the fireworm was observed from the use of the nicotine-sulphate-and-soap solution, especially on the McFarlin variety. On

plats E, F, G, and H, but particularly on H, it was noticed that the berries were generally much larger and the vines of a brighter green than those on the other plats. Wherever this spray solution was used it seemed to have a fertilizing or stimulating effect on the vines, making them grow more luxuriantly and produce larger sized berries than they otherwise would have done.

RECOMMENDATIONS FOR CONTROL.

REFLOWING.

As recommended by Scammel,¹³ reflowing, where it is possible to do it properly, will doubtless be as effective in controlling the black-head fireworm on the Pacific coast as elsewhere. While no experiments were performed along this line on the Pacific coast, yet for the benefit of those growers who may be able to equip their bogs for reflowing and wish to employ this method of control, it might be stated that the proper time to reflow for the fireworm is when the majority of the larvæ of the first brood are about full grown, as at this time they can be more easily and quickly killed than in any other stage.¹⁴ On the bogs in the vicinity of Seaview, Wash., the majority of the larvæ of the first brood are full grown near the middle or latter part of May, but if the bog is winter flowed, i. e., covered with water in the wintertime, this date would vary according to the date this winter flood was drawn from the bog. In reflowing, the water should completely cover the vines and be held there for at least 48 hours in order to kill the greatest number of larvæ. Any grass or other objects projecting above the surface should be removed so that the larvæ can not crawl up to the tops and thus escape the flood.

SPRAYING.

Spraying with a solution of 40 per cent nicotine sulphate and water, with soap as a spreader, has been found to be the most effective method of controlling the blackhead fireworm on the Pacific coast.

HOW TO PREPARE THE NICOTINE SULPHATE SPRAY.

Any nicotine solution containing 40 per cent of nicotine sulphate is suitable in the preparation of this spray, and any kind of soap *free from uncombined oils or greases* may be used as a spreader. The proportions found most effective against the fireworm are: One part of 40 per cent nicotine sulphate to 800 parts of water, with 2 pounds of soap to each 50 gallons of the liquid. Solutions containing a greater proportion of nicotine sulphate than 1 to 800 will do no

¹³ Scammel, H. B. Cranberry Insect Problems and Suggestions for Solving Them. U. S. Dept. of Agr., Farmers' Bulletin 860, p. 7-8. 1917.

¹⁴ Ibid, p. 8.

harm, but on the other hand will give no better control, and if used at the rate of 1 part to 1,000 parts of water with the above proportion of soap, about one-third to one-half more gallons per acre should be used and then only on light infestations.

To make 200 gallons of this material the tank should be run about three-fourths full of water while washing through the sieve 8 pounds of the soap, which should be previously broken up in warm water or otherwise thoroughly softened. One quart of the 40 per cent nicotine sulphate should then be poured slowly into the tank with the remainder of the water necessary to make up the 200 gallons while the whole solution is being thoroughly agitated to insure proper mixing of the ingredients. It is then ready to be applied to the vines.

The nicotine sulphate is added last and in a diluted form to prevent the precipitate which forms when concentrated solutions of nicotine sulphate and soap are brought together and which decreases the effectiveness of the spray solution.

If these materials are to be combined with Bordeaux mixture, the proportions of nicotine sulphate and soap and the process of mixing is the same as though water were used to make the solution as described above. Nicotine sulphate can be mixed with lime-sulphur solutions in all the usual proportions, but *no soap should be added to a solution containing lime-sulphur or any other similar compound*, else a disintegration of the ingredients will take place which will not only weaken the effectiveness of the combination but also may cause severe injury to the cranberry vines.

THE AMOUNT TO BE USED PER ACRE.

Depending on the severity of the infestation, not less than 250 to 300 gallons of this solution should be used in spraying an acre of vines, as good control can not usually be secured with a less amount than this. If it is preferred to use 40 per cent nicotine sulphate at the rate of 1 to 1,000, rather heavy applications will have to be made, less than 400 or 500 gallons per acre never being used.

TYPE OF NOZZLE.

The use of a nozzle, preferably of the large eddy-chamber type shown in figure 13, equipped with a disk, throwing a *medium-fine* mist which will quickly and easily wet the terminal whorl of leaves on the tip of the uprights, is to be recommended. The Vermorel type of nozzle is too small and throws too fine a mist (fig. 15), most of which is driven away by the wind and thus fails to give the desired results. The spray gun should be used only on very large and thinly infested bogs and then great care must be taken to see that no uprights are missed and that a uniform application is made with the pressure at the tank never less than 200 pounds per square inch.

PRESSURE.

The pressure need not be higher than about 200 or 250 pounds at the tank, depending upon the size and length of pipe or hose through which the liquid has to be forced and the number and kind of nozzles used.

TIME AND NUMBER OF APPLICATIONS.

For vines which are only lightly infested three applications are recommended. The *first* of these should come when the new upright growth is from one-half to three-fourths of an inch long; that is,



FIG. 15.—A spray boom for holding 10 Vermorel nozzles. Note the unevenness of the spray cone and the necessity of considerable walking and dragging of hose over vines in spraying. Not a good type of outfit to use.

when large numbers of the young larvæ are proceeding to and some working in or near the new unfolding leaves at the tips of the up-rights. The *second* should be applied shortly after the first blossoms appear, or, in other words, at the early "hook stage." This may come from 10 days to 3 weeks after the first application, depending on the weather; it is designed to kill the next group of larvæ before they conceal themselves in the new growth. The *third* application should be made when the vines are in full bloom, or about 2 weeks after the second application, the object being to keep the young larvæ from destroying blossoms and newly forming berries.

Vines which are rather heavily infested will require the first year all three applications, as outlined above, and an additional *fourth* application, which should be made during the first two weeks of July. This last spray is designed to give protection, both to the berries and to the upright tips in which the fruit buds for the following year's crop are forming, against late hatching larvæ of the first generation and the first larvæ of the second generation. It is also designed to kill many of the moths of the first generation, and it should, therefore, be timed so as to come within the limits mentioned, as it is about this time that the moths are flying in largest numbers. By careful spraying with an outfit like that shown in figure 13, one application at this time will clean a bog of fireworm moths and thus prevent a large number of the eggs of the second generation from being deposited.

KIND OF EQUIPMENT.

A 50-gallon wheel-barrel outfit, with a strong pump, will usually be found sufficiently large for bogs up to several acres in extent. For larger bogs the power outfits of various sizes will be most economical, and in order to avoid dangerous delays at spraying time one should be sure that the parts are not only durable but easily accessible and replaceable as well.

Any arrangement of nozzles and manner of spraying the bog that will insure thorough application of the spray as previously outlined and at the same time cause a minimum injury to the vines from walking or dragging the hose over them will be satisfactory.

After a consideration of the factors which influence the hatching and development of the blackhead fireworm (see pages 8-9), it would seem reasonable to suppose that a covering of water held over the vines until late in the spring, say until about April 10 to 15, together with the thinning out of thickly vined bogs, would have a very beneficial effect. It would also facilitate good control work by grouping the hatching of the larvæ. In view of the fact that it is also considered a good horticultural practice on the Pacific coast, this method of bog management in connection with spraying is to be recommended wherever it is practicable, especially on bogs which are badly infested with fireworms.

SUMMARY AND CONCLUSIONS.

The blackhead fireworm (*Rhopobota naevana* Hübner) is the most important pest of the cranberry on Pacific coast bogs. It is found also on native cranberry vines well isolated from cultivated bogs, but was doubtless introduced on these cultivated bogs on cuttings from eastern cranberry districts. So far as known on the Pacific coast, it feeds only on the cranberry.

The phenology of the cranberry in that locality is quite variable. Usually on the earliest varieties, such as the McFarlin and Early Black, buds begin to break and the new growth begins to push forth about the beginning of April. The new upright growth is about three-fourths of an inch long by the middle of April, the blossoms are in the "hook stage" in about a month more, and full bloom comes about the beginning of June. The late varieties, such as the Howe, are more variable, but the new growth starts the beginning of May and attains three-fourths of an inch in about a week. The majority of the blossoms are in the "hook stage" about the middle of June and fully opened by the latter part of June or early July.

Almost none of the bogs on the Pacific coast are ever completely covered with water, and the seasonal temperature is comparatively equable. These conditions, coupled with the small number of parasites, enable this pest to be very destructive, the larvæ feeding on the buds, foliage, blossoms, and fruit throughout the growing season.

The insect passes the winter in the egg stage. The eggs are quite small, smooth, and slightly oval, with the center slightly raised or rounded. They are lemon and orange yellow and are deposited singly or in small irregular groups on the undersides of the cranberry leaves. The young larva on hatching leaves the egg through a rent near the edge of the upper side and then feeds for a few days on the leaf or leaves near by. Later it proceeds to the tip of the upright, there feeding on the unfolding buds and blossoms.

By rearing the insect from the egg stage in an outdoor shelter where conditions were maintained which approached those naturally found on the cranberry bog, it was found that there are annually two full generations and sometimes a partial third. Temperature, depth of vines, and drainage are the three most important factors in the hatching and development of the fireworm.

The mature larva is very active, is about one-fourth of an inch long, dark greenish yellow, with a coat of dark olive-green above, and with head and thoracic shield varying from light brown to black. The ravages of the larvæ result in a burnt appearance of the vines, as if a fire had swept over the bog. Hence the common name "blackhead fireworm."

Nearly all the larvæ change to pupæ in loosely constructed cocoons in old leaves and trash beneath the vines. The pupa is a little less than one-fourth of an inch long and of a brownish amber color.

The adult or moth moves in quick, jerky flights, is about the same length as the mature larva, and has characteristic markings of a single row of short, alternating brownish and silver-gray bars running diagonally to the front margin of the first pair of wings. The males have an irregular dark area near the front margin on the underside of the second or lower pair of wings.

Naturally the moths do not migrate more than a few yards, but, helped by a strong wind, it is possible for them to be carried as far as several hundred feet at a flight. In the egg stage, the fireworm can be disseminated over a bog in two other ways—namely, on leaves floating on the water which naturally gathers on the bog in the winter time and on leaves on cuttings used in planting.

Egg laying usually commences from one to several days after copulation and closely follows the temperature, the largest number being deposited between 3 and 9 p. m.

The larvæ of the first generation appear on the bogs in greatest abundance about the latter part of May, the pupæ toward the middle of June, and the moths about the first or second week in July.

A fungous disease which attacks the pupæ in their cocoons in the old leaves beneath the vines is responsible for the death of a large number, especially on old and badly infested bogs. Spiders and ladybird beetles also kill a large number of the fireworm moths and larvæ.

Control experiments seeking to establish the best kind of spray materials, the proper number of applications, and the most effective manner of applying them, were conducted on small and large scales under natural bog conditions. Forty per cent nicotine sulphate at the rate of 1 part to 800 parts of water, with the addition of fish-oil soap at the rate of 2 pounds to every 50 gallons, used at the rate of about 300 gallons to the acre, was found to be the most effective spray material against the fireworm. Forty per cent nicotine sulphate, used at the rate of 1 part to 1,000 parts of water with the addition of fish-oil soap, 2 pounds to every 50 gallons, was nearly as effective.

Nicotine oleate made by mixing $2\frac{1}{2}$ parts of a solution containing 40 per cent *free nicotine* with $1\frac{3}{4}$ parts of commercial oleic acid, or red oil, and used at the rate of 1 part to 400 parts of water, applied three times at the rate of about 300 to 400 gallons per acre, was found nearly as effective as 40 per cent *nicotine sulphate* 1 to 800 with fish-oil soap 2 to 50, applied three times at the minimum rate per acre. Arsenate of lead proved of little or no value in the control of the fireworm. Fish-oil soap, 2 pounds to 50 gallons of solution, was a much better spreader for spray solutions on cranberry foliage than glue, which was used at the rate of 1 pound to 200 gallons. One compound containing a high percentage of crude carbolic acid and usually employed as a disinfectant gave little or no control.

Demonstration spraying experiments were conducted in which 40 per cent nicotine sulphate 1 to 800, with fish-oil soap 2 pounds to 50 gallons, was used. Four applications on McFarlin vines, in which the eddy-chamber mist type of nozzle was used, gave the best results, producing the largest yield of berries and the highest percentage of berries free from fireworm injury.

The spray gun, used in spraying McFarlin vines four times, gave the next highest yield, but the third highest percentage of uninfested fruit of this variety.

The results of four applications with the Bordeaux type of nozzle on the McFarlin variety ranked third in yield and second in percentage of uninfested McFarlin berries.

No very definite conclusions based on yield can be drawn from the experiments of spraying on the Howe variety on account of injury by the fireworm on the plats in 1918 and frost in the spring of 1919. Of the Howe plats receiving three applications, however, the one sprayed with the Bordeaux type of nozzle resulted in the highest percentage of fruit free from fireworm injury, that sprayed with the mist type of nozzle was second, and that with the spray gun was third.

Four applications with the spray gun on the Howe variety gave the highest percentage of uninfested fruit of all the plats on which the spray gun was used.

Generally speaking, four applications gave better results than three.

On bogs that can be reflowed, a complete covering of the vines with water for not less than 48 hours during the middle or latter part of May is recommended as a help in the control of the fireworm. Since most of the bogs on the Pacific coast, however, are managed as dry bogs, spraying with 40 per cent nicotine sulphate 1 to 800, with the addition of fish-oil soap at the rate of 2 pounds to every 50 gallons, is recommended as the most feasible method of control of the black-head fireworm in that locality.

Between 250 and 300 gallons of this material should be used per acre. In making up the nicotine sulphate spray, the fish-oil soap should be mixed with about half the quantity of water and the required amount of nicotine sulphate added with the remainder of the water to prevent the formation of a precipitate which decreases the effectiveness of the spray solution and which might also clog the nozzles and possibly injure the vines. This spray solution can be combined with Bordeaux mixture or lime-sulphur in the usual proportions, in which case the process of mixing is the same as though water were used. *No soap, however, should be added if the mixture contains lime-sulphur.* The large eddy-chamber type of nozzle, throwing a medium fine mist, at a pressure of about 200 pounds at the tank, should be used; other types of nozzles may not only give unsatisfactory results but may also injure the blossoms. The spray gun should be employed only on lightly infested bogs.

Vines which are lightly infested should have three applications of the nicotine sulphate spray, the first one when the new upright growth has reached a length of about three-fourths of an inch, the second when the blossoms are in the early "hook stage," and the third when the vines are in full bloom.

Heavily infested vines should have all of these three applications at the times mentioned and an additional fourth application during the first two weeks of July. In the application of this last spray an effort should be made to hit as many moths as possible with the spray solution.

A 50-gallon barrel outfit on wheels, with a strong pump, will be found desirable for small bogs. For bogs larger than several acres in area, power outfits should be used.

In making the applications great care should always be exercised to prevent injury to the vines.

SYSTEMATIC DESCRIPTION OF RHOPOBOTA NAEVANA HÜBNER.

By CARL HEINRICH, *Bureau of Entomology.*

SYNONYMY.

Tortrix naevana Hübner, in *Samm. Eur. Schmett.*, v. 5, Tort., pl. 41, fig. 261, 1814.

Tortrix unipunctana Haworth, in *Lep. Brit.*, p. 454, 1812.

Lithographia geminana Stephens, in *List Brit. Mus.*, Pt. X, Lep., p. 99, 1852.

? *Sciaphila luctiferana* Walker, in *Cat. Brit. Mus.*, Lep., ser. 6, pt. 28, p. 342, 1863.

Anchylopera vacciniana Packard, in *Guide Stud. Ins.*, p. 338, 1869.

Rhopobota naevana Staudinger and Rebel, in *Cat. Lepidop.*, Aufl. 3, theil 2, p. 127, 1901.

Eudemis vacciniana Dyar, in *List No. Amer. Lepidop.*, p. 466, no. 5238, 1902.

Rhopobota naevana Dampf, in *Iris*, bd. 21, p. 304-329, 1908.

GENERAL CHARACTERS.

ADULT.

Plate I, A; Plate II, A, B, C.

Thorax smooth. Forewing smooth; termen deeply concaved between veins 4 and 6; apex pointed but not falcate; 12 veins; 7 and 8 stalked; 10 from cell midway between 9 and 11; 9 approximate to 8; 11 from cell at or just before middle of cell; upper internal vein of cell nearly obsolete, when distinguishable, from between 9 and 10; 3, 4, and 5 closely approximate at termen; 2 bent up slightly at outer third; costal fold in male absent. Hindwing with 8 veins; 6 and 7 approximate toward base; 3 and 4 stalked; male with a shading of coarse black scales on underside of wing along upper vein of cell. Male genitalia as figured; harpes undivided, with rudimentary clasper present and on outer surface just above lower margin a row of rather long, stout spines; uncus present, bifurcate, arms widely separated, rather short, weakly chitinized and slipper shaped; gnathos reduced and fusing with socii; socii greatly developed, porrected, extremities meeting in hairy knoblike projection; aedoeagus straight, moderately long, fairly stout.

PUPA.

Plate I, B, C.

Slender, abdominal segments gradually tapering; a double row of spines on dorsum of abdominal segments 3 to 6 inclusive, a single row on abdominal segments 2, 7, 8, 9, and 10; first abdominal segment smooth; wings extending to or slightly beyond ventro-caudal margin of fourth abdominal segment; cephalic end bluntly rounded; vertex distinct, as broad as prothorax; labrum, mandibles, and maxillary palpi well developed; maxillary palpi extending to proximo-lateral angles of maxillæ; maxillæ less than half the wing length; labial palpi half the length of maxillæ; prothoracic femora and mesothoracic

coxae exposed; antennae and mesothoracic legs not reaching to end of wings; several strong setae on tenth abdominal segment; a pair of stout setae on each side of anal rise; anal rise unarmed; body setae otherwise weak and hardly distinguishable; spiracles slightly reduced; anal and genital openings slitlike in both sexes; cremaster absent.

LARVA.

Plate II, D; Plate III, A-C, E-G.

Cylindrical, slender, very slightly tapering at caudal end. No secondary hair. Legs and prolegs normal. Crochets uniorbital, in a complete circle. Anal fork present, reduced. Prothoracic shield broad, divided. Spiracles round, moderate; that on eighth abdominal segment slightly higher than those on abdominal segments 1 to 7, not over one and one-half times as large, same size as that on prothorax. Skin evenly and appreciably scobinate.

Body setae moderately long; tubercles broadly chitinated; IV and V on abdominal segments 1 to 8 under the spiracle and approximate; prespiracular shield of prothorax elongate, large, bearing three setae (III, IV, and V) in a longitudinal line; group VI bisetose on prothorax, unisetose on mesothorax and metathorax, greatly reduced and closely approximate to IV and V on abdominal segment 9; III antero-ventrad of the spiracle on eighth abdominal segment, directly over the spiracle on abdominal segments 1 to 7; IIIa not distinguishable; on thoracic segments 6 setae in group VII; VII bisetose on abdominal segments 7, 8, and 9; ninth abdominal segment with 9 setae in a nearly vertical line, paired setae of group II close together on same chitination on dorsum, I and III closely approximate; on abdominal segments 1 to 8 II latero-caudad of I; prothorax with II^a slightly higher than I^a, closer to II^b than to I^a, II^b above the level of puncture z; I^b nearer to puncture z than to I^c, II^c about equidistant from I^b and I^c, puncture y directly caudad of I^a, puncture x dorso-caudad of I^a and on the level of II^a.

Head capsule spherical, nearly square in outline viewed from above; slightly wider than long; greatest width well back of middle of head; incision of dorsal hind margin slight, about one-fourth the width of the head; distance between dorsal extremities of hind margin about half the width of the head. Frons broad, triangular, longer than wide, reaching beyond middle of the head. Adfrontal sutures extending to incision of dorsal hind margin. Longitudinal ridge very short, less than one-third the length of the frons.

Ocelli six; lenses well defined.

Epistoma normal.

Frontal punctures close together; well forward of frontal setae; distance from frontal seta (F¹) to first adfrontal seta (Adf¹) about equal to distance separating adfrontal setae (Adf¹ and Adf²); Adf² anterior to beginning of longitudinal ridge; puncture Adf^a between and about equidistant from Adf¹ and Adf².

Epicranium with the normal primary setae and punctures and with a row of three ultraposterior setae and one puncture. Anterior setae (A¹, A², and A³) in a line with lateral setae (L¹); anterior puncture (A^a) closely approximate to and posterodorsad of A². Posterior setae (P¹ and P²) and puncture (P^b) in a line with first adfrontal seta (Adf¹); P¹ about middle of head, on the level of adfrontal puncture and lateral seta (L¹); P^b between and about equidistant from P¹ and P²; puncture P^a lying between P¹ and L¹, approximate to the latter. Lateral puncture directly posterior to L¹, remote. Ocellar setae (O¹, O², O³) well separated, forming a right angle; O¹ lying below and between ocelli II and III; O² postero-ventrad of ocellus I, in a line with ocelli I and II

and seta A^1 ; O^3 ventrad of O^2 , remote; ocellar puncture not distinguishable. Subocellar setæ (SO^1 , SO^2 , and SO^3) triangularly placed; puncture SO^3 approximate to and equidistant from SO^2 and SO^3 . Genal puncture (G^a) anterior to the seta (G^1).

Labrum with median incision broadly triangular, rather shallow; median setæ (M^1 , M^2 , M^3) triangularly placed; M^2 postero-laterad of M^1 and closer to M^1 than to M^3 ; La^1 directly posterior of and approximate to La^2 , behind the level of M^2 ; La^2 on the level of M^1 ; La^3 and M^3 on the same level near anterior margin of labrum; puncture approximate and posterior to M^1 .

Epipharyngeal shield narrowly bordering the median incision, not sharply defined. Epipharyngeal setæ triangularly grouped, rather close together, narrow, moderately long. Epipharyngeal rods indicated only by their short posterior projections.

EGGS.

Plate III, D.

Oval, flat, scale-like, iridescent; deposited singly.

SPECIFIC DESCRIPTION.

ADULT.

Palpi brownish on outer sides, grayish white on inner and upper sides. Face and head grayish, more or less suffused with fuscous. Thorax fuscous. Forewings grayish, cross-marked with fuscous or, in some specimens, dark reddish brown; the brown area forming an outwardly angulated basal patch somewhat marked with gray or whitish scales and covering the basal third of the wing; a similar brown suffusion forming an ill-defined fascia extending from just beyond middle of costa to tornus, considerably wider on dorsum than on costa; a narrow brown terminal line, following the contour of termen and broadening at apex to a distinct brown spot; a fainter angulate brown line from costa dividing the ocellus; on costa six or seven pairs of short, somewhat obscure, white geminate marks separated by distinctly brownish shadings; ocellus metallic gray with longitudinal markings. Hindwings fuscous. Legs fuscous with inner sides white or grayish and tarsi annulated with white. Alar expanse, 9-14 mm.

PUPA.

Length, 5-6 mm.; yellow or yellowish brown, not appreciably darker at extremities but with sutures and caudal margins of abdominal segments brown; dorsal abdominal spines brown, arranged as shown in Plate I, C.

LARVA.

When full grown, 10-11 mm. long by 1 mm. broad. Body sordid white; the scobination blackish, giving the entire larva a pale smoky fuscous color; chitinized areas about body tubercles white except on prothorax where they are dark brown, in some specimens almost black; thoracic shield brown or blackish brown; median dividing line pale yellow; chitinized parts of thoracic legs black or blackish brown; anal shield yellowish; anal fork two-pronged, small and easily overlooked; body hairs brown; crochets 36-42, brown, weaker at the cephalic end of the circle and increasing in length toward the caudal margin where the longest are over twice as long as the shortest at the anterior margin (Pl. III, C'). Head yellow, more or less suffused with dark brown, especially on ventral side; a distinct brownish patch at posterior lateral angle of epicranium; chitinized parts of trophi black or blackish brown; ocellar pigment black, continuous under the ocelli; lenses white.

Egg.

Shining grayish white; entire surface finely and evenly faceted, smooth.

This species has appeared in our economic literature and lists under the name *vacciniana* Packard, and has been held to be an American species distinct from the European *naevana* Hübner, although the synonymy has been long suspected. A careful comparison of the genitalia and external characters of the two shows them to be one species. Another American species, *Epinotia ilicifoliana* Kearfott, also should be referred to the genus *Rhopobota* as a variety of *R. naevana*. In genitalia it is identical but differs somewhat in pattern. Dampf, in a very excellent study of their genitalia, has shown the synonymy of the two European forms *naevana* Hübner and *geminana* Stephens.

The larva of *Rhopobota naevana* is easily confused with another cranberry feeder, *Peronea minuta* Robinson, which it superficially resembles. The latter, however, can be at once distinguished by the arrangement of setæ I, II, and III on the ninth abdominal segment and its different anal fork. In *R. naevana* I and III are closely approximated and on a single chitination and the anal fork is two-pronged and very small; whereas in *P. minuta* I is well separated from III, about equidistant from both II and III, and both I and III are on separate chitinizations and the anal fork is five or six pronged, large, and rather conspicuous.

EXPLANATION OF PLATES.

PLATE I.

Rhopobota naevana:

A.—Adult.

C.—Pupa, dorsal view.

B.—Pupa, ventral view.

Explanation of symbols applied to pupa.

a = antenna.
ao = anal opening.
at = invaginations for anterior arms of tentorium.
ex² = coxa of mesothoracic leg.
es = epicranial suture.
f¹ = femur of prothoracic leg.
ge = glazed eyepiece.
go = genital opening.
lb = labrum.
l¹ = prothoracic leg.
l² = mesothoracic leg.

l³ = metathoracic leg.
lp = labial palpi.
md = mandible.
mp = maxillary palpus.
ms = mesothorax.
mt = metathorax.
mx = maxilla.
p = prothorax.
se = sculptured eyepiece.
v = vertex.
1 to 10 = abdominal segments 1 to 10.

PLATE II.

Rhopobota naevana:

A.—Denuded forewing of female moth, showing venation.

B.—Denuded hindwing of female moth, showing venation.

C.—Male genitalia of moth; ventral view of organs spread.

D.—Setal map of first and second thoracic, and third, eighth, and ninth abdominal segments of larva, showing arrangement of body setæ.

Explanation of symbols applied to genitalia.

Ae = ædæagus.	Hp = harpe.
An = anellus.	Si = socii.
Cl = clasper.	U = uncus.
Cn = cornuti (spines on penis).	Vm = vinculum.
Gn = gnathos.	

PLATE III.

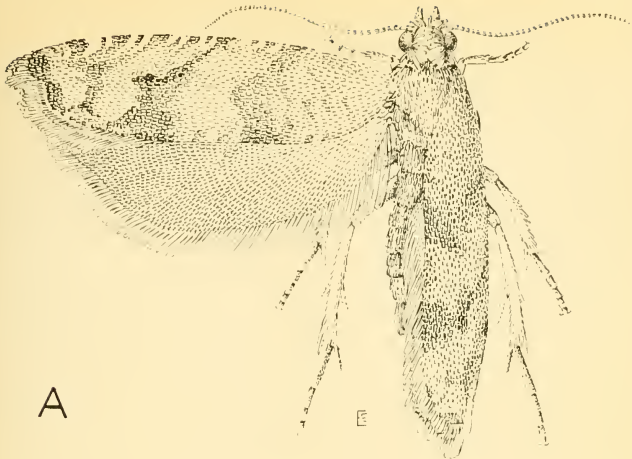
Rhopobota naevana:

- A.—Dorsal view of head capsule of larva, showing setal arrangement.
 B.—Lateral view of head capsule of larva, showing setal arrangement.
 C.—Arrangement of crochets of abdominal proleg of larva.
 D.—Egg, greatly magnified.
 E.—Ventral view of tenth abdominal segment of larva, showing anal fork.
 F.—Labrum of larva.
 G.—Epipharynx of larva.

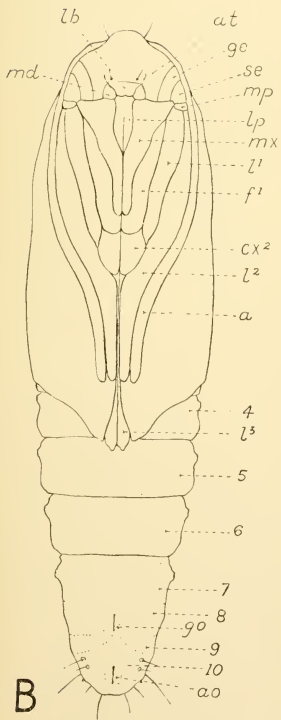
Explanation of symbols applied to larva.

- A¹, A², A³, A^a=setæ and puncture of anterior group of epicranium.
 Adf¹, Adf², Adf^a=adfrontal setæ and puncture of epicranium.
 ADFR=adfrontal ridge of larval head.
 ADFS=adfrontal suture of larval head.
 Af=anal fork.
 E¹, E²=epistomal setæ.
 ER=epipharyngeal rod.
 ES=epipharyngeal shield.
 ET=epipharyngeal setæ.
 F¹, F^a=frontal seta and puncture of epicranium.
 FR=frons of epicranium.
 G¹, G^a=genal seta and puncture of epicranium.
 L¹, L^a=seta and puncture of lateral group of epicranium.
 La¹, La², La³=lateral setæ of labrum.
 Lp=labral puncture.
 LR=longitudinal ridge of epicranium.
 M¹, M², M³=median setæ of labrum.
 O¹, O², O³=setæ of ocellar group of epicranium.
 P¹, P², P^a, P^b=setæ and punctures of posterior group of epicranium.
 SO¹, SO², SO³, SO^a=setæ and puncture of subocellar group of epicranium.
 X=ultraposterior setæ and puncture of epicranium.

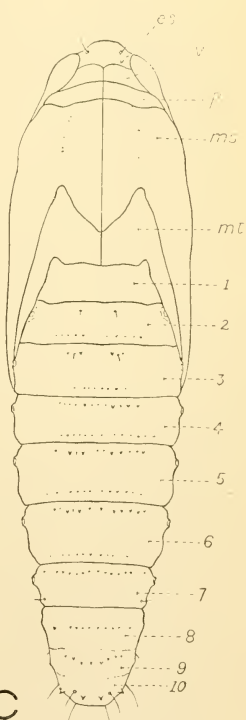
Drawings on Plates I, II (except C), and III were made under the author's supervision by Miss E. Edmonston, of the Bureau of Entomology. The male genitalia (Pl. II, C) were drawn by Miss Ada F. Kneale, formerly of the Bureau of Entomology.



A

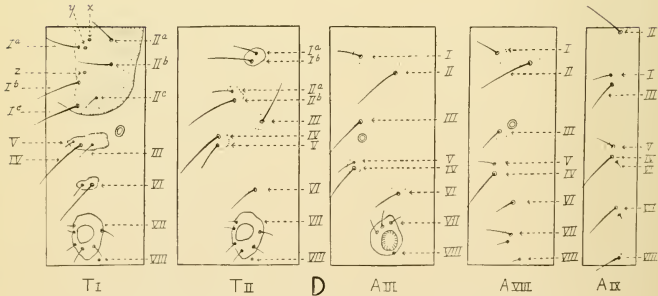
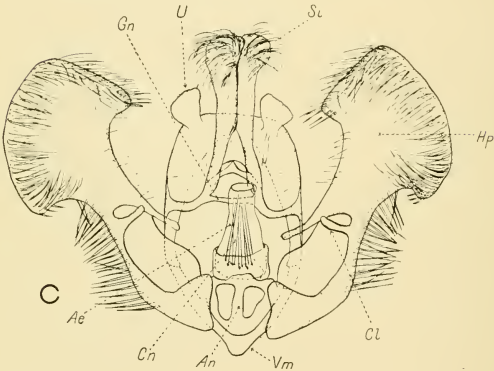
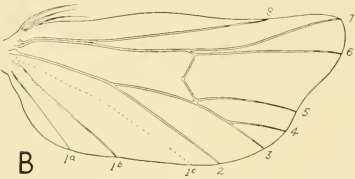
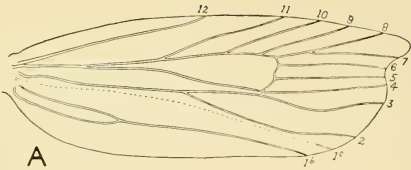


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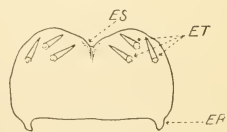
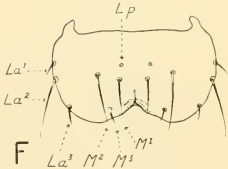
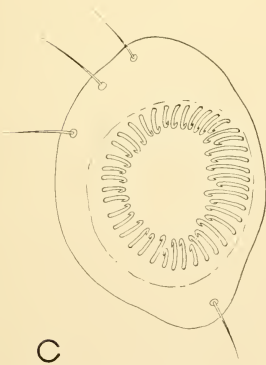
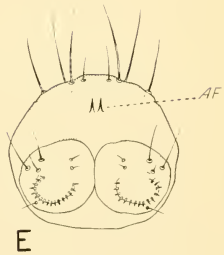
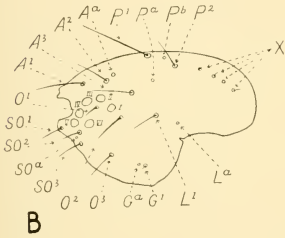
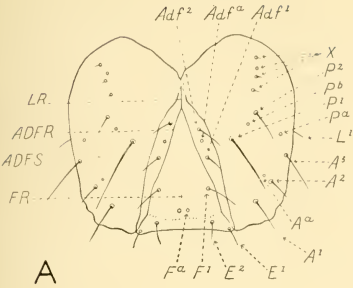


C

THE BLACKHEAD FIREWORM OF CRANBERRY.



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INSECT

UNITED STATES DEPARTMENT OF AGRICULTURE



BULLETIN No. 1035



Contribution from the Bureau of Entomology
L. O. HOWARD, Chief

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THE RED SPIDER ON THE AVOCADO.

By G. F. MOZNETTE, *Assistant Entomologist, Tropical and Subtropical Fruit Insect Investigations.*

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INTRODUCTION.

The red spider *Tetranychus yothersi* McG. is one of the foremost enemies of the avocado and attacks a number of other plants and fruit trees in Florida. It was recognized by avocado growers as an important enemy of this fruit as early as 1909, and since that time the damage caused by it has become more pronounced each year. This bulletin records the work with this spider during the years 1918 and 1919 and the results of cooperative spraying experiments in connection with the station established by the Bureau of Entomology in 1917 at Miami, Fla., for the investigation of various insect enemies of the avocado and other subtropical fruits characteristic of that region.

ECONOMIC IMPORTANCE.

In groves where the red spider is abundant the trees frequently become defoliated prematurely during the winter season. This generally results in an abnormal development of bloom the following spring and the weakened trees are unable to set and hold a full crop

of fruit. To sustain the bloom and aid in the setting of fruit the older foliage should remain on the trees until a sufficient amount of new growth apparently arising from the inflorescence (fig. 1) has been produced in the spring to take its place.

NATURE OF INJURY TO FOLIAGE.

The red spider punctures the leaves and sucks the contents, forming white spots at the point of attack. As these feeding punctures and



FIG. 1.—Avocado blossom cluster with older leaves which sustain the bloom, and developing new growth.

resultant white spots become more in evidence a gradual burning and reddening of the foliage results, as if scorched by fire (Pl. I, A, B). The foliage so attacked soon falls, giving the tree a naked appearance (fig. 2).

FOOD PLANTS AND DISTRIBUTION.

This red spider was first named and described by E. A. McGregor¹ from specimens on camphor (*Cinnamomum camphora*) leaves sent

¹ MCGREGOR, E. A. FOUR NEW TETRANYCHIDS. In *Ann. Ent. Soc. Amer.*, v. 7, no. 4, p. 355-357, 1914.



APR 11 1916

THE RED SPIDER OF THE AVOCADO

A, Avocado leaf with characteristic reddening and scorched appearance caused by the red spider; *B*, Uninjured avocado leaf.

him in 1914 by W. W. Yothers, of Orlando, Fla. The writer has found it attacking both the West Indian and Guatemalan varieties of avocados (*Persea gratissima*), being particularly injurious to the more tender West Indian types. It occasionally causes considerable injury to the mango (*Mangifera indica*) and in many sections of northern Florida to the camphor and Australian silk oak (*Grevillea*



FIG. 2.—Defoliated avocado tree during midwinter, the result of attacks on foliage by the red spider.

robusta), to the foliage of which it imparts the same discoloration that it causes to the avocado. It has also been collected in Florida on a species of eucalyptus (*Eucalyptus* sp.). In addition to these host plants, the writer has at times collected the red spider on *Terminalia arjuna*, *Annona squamosa*, *Cucumis sativus*, and *Leacorea paniculata*—the latter a plant growing quite commonly in the hammocks of southern Florida.

Mr. E. A. McGregor reports it as attacking also the American elm (*Ulmus americana*) and two other varieties of elm (*Ulmus* spp.), the willow (*Salix* sp.), the white oak (*Quercus alba*), and the pecan (*Hicoria pecan*), at Batesburg, S. C. He records it also on elm (*Ulmus* sp.) from Columbia, S. C., and Laurinburg, N. C. These records indicate a probable wide distribution of this red spider through the South. In Florida the writer has found this species along both the east and west coasts, including Miami Beach, Miami, Biscayne Key, Homestead, West Palm Beach, Florida City, Fort Myers, Bradentown, Oneco, and Winter Haven.

DESCRIPTION AND HABITS.

THE ADULT FEMALE.

In appearance the adult female (fig. 3, *f*) is similar to most red spiders which attack various other crops. It is small, of a rusty-red

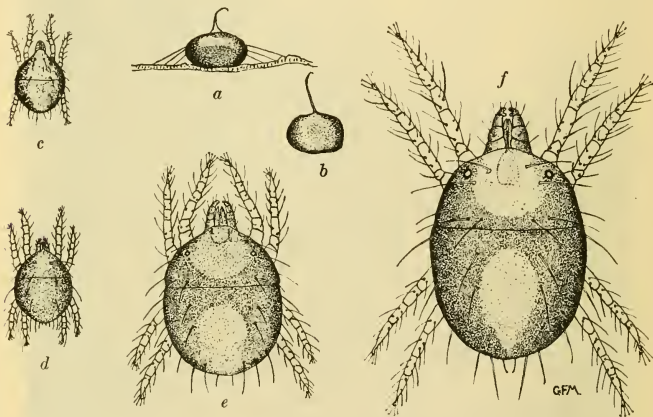


FIG. 3.—The avocado red spider: *a*, *b*, Egg; *c*, larva; *d*, first nymph; *e*, second nymph; *f*, adult female.

color, averaging 0.30 mm. in size. The abdomen joins the cephalothorax, formed by the fusion of the head and thorax, at its full width and extends over the portion to which the posterior pair of legs is attached. The body and legs are covered with bristles.

THE MALE.

The body of the male is slender and pointed toward the tip of the abdomen and is somewhat smaller than that of the female. The legs are slightly darker and longer than those of the female. The eyes are red and somewhat more conspicuous than those of the female. It averages 0.22 mm. in length.

THE EGG.

The egg (fig. 3, *a, b*) is globose in shape, smoky amber in color, and bears a stalk at its apex. Guy fibrils are occasionally seen connecting the egg with the leaf.

The eggs are deposited singly and when the leaf first becomes infested are generally found located along the midrib at the base of the leaf. As the activities of the mites increase with succeeding generations, the eggs may be found scattered over the entire leaf.

The incubation period varies according to the temperature and general climatic conditions. (See Table 1.) During midwinter, with mean daily temperatures between 60° and 70° F., incubation requires from 7 to 11 days. During April and May the incubation period averaged from 4 to 5 days with mean temperatures between 70° and 80° F., in rearing experiments with this species. In hatching, the shell of the egg splits more or less completely around and the larva easily extricates itself. During the height of the red spider season leaves will be observed heavily covered with hatched eggshells which adhere to the leaf and impart to it a whitish cast.

TABLE 1.—Length of the egg stadium.

No.	Date deposited.	Date hatched.	Duration.	Mean temperature.	No.	Date deposited.	Date hatched.	Duration.	Mean temperature.
			<i>Days.</i>	<i>° F.</i>				<i>Days.</i>	<i>° F.</i>
1	Oct. 15	Oct. 20	5	78	7	Jan. 21	Feb. 1	11	60
2	Oct. 22	Oct. 26	4	77	8	Feb. 15	Feb. 22	7	70
3	Nov. 8	Nov. 13	5	72	9	Mar. 15	Mar. 20	5	72
4	Nov. 30	Dec. 8	8	70	10	Apr. 1	Apr. 5	4	75
5	Dec. 18	Dec. 25	7	65	11	May 31	June 5	5	76
6	Jan. 1	Jan. 11	10	58	12	July 11	July 15	4	79

THE LARVA.

The newly hatched larva (fig. 3, *c*) is round, very light yellow, possesses six legs, and in size does not exceed that of the egg from which it emerged. It is very delicate, and a marked characteristic is its possession of conspicuous carmine eyes. During the process of development and feeding the young creatures commence to change color. The larva measures 0.17 mm. in length on an average.

As with practically all mites the larva stage is divided into an active and a quiescent period. The former is passed while the larva is feeding and the latter in preparation for the first molt. The time spent in the quiescent period of the larva stage averages in most instances only a few hours. The average length of the larval period is 2.58 days.

TABLE 2.—*Length of the larval stadium.*

No.	Date of hatching.	Date molted.	Duration.	Mean temperature.	No.	Date of hatching.	Date molted.	Duration.	Mean temperature.
			<i>Days.</i>	<i>° F.</i>				<i>Days.</i>	<i>° F.</i>
1	Oct. 18	Oct. 20	2	76	7	Feb. 1	Feb. 4	3	65
2	Oct. 28	Oct. 31	3	77	8	Feb. 22	Feb. 24	2	70
3	Nov. 15	Nov. 19	4	75	9	Mar. 20	Mar. 23	3	72
4	Dec. 10	Dec. 13	3	70	10	Apr. 5	Apr. 7	2	75
5	Dec. 25	Dec. 28	3	68	11	June 5	June 7	2	76
6	Jan. 11	Jan. 15	4	63	12	July 13	July 15	2	79

THE FIRST NYMPHAL STAGE (THE PROTONYMPH).

The first nymphal stage (fig. 3, *d*) differs from the larva in having four pairs of legs instead of three and is slightly increased in size. The extra pair of legs appears behind the last pair of legs of the larva. The segments of the legs become longer, as do likewise the bristles on the body and legs. The color of the body darkens. The abdomen in this stage becomes elongated as compared to the larva. The average length of the protonymph is 0.25 mm.

For the most part the habits of the nymphal stage are similar to those of the larva. As with the larval stage the protonymph stage is divided into an active feeding period and a quiescent period preparatory to molting. The average length for the first nymphal stage is 2.8 days.

TABLE 3.—*Length of the first nymphal stadium.*

No.	Date emerged.	Date molted.	Duration.	Mean temperature.	No.	Date emerged.	Date molted.	Duration.	Mean temperature.
			<i>Days.</i>	<i>° F.</i>				<i>Days.</i>	<i>° F.</i>
1	Oct. 20	Oct. 22	2	76	7	Feb. 4	Feb. 6	2	65
2	Oct. 31	Nov. 3	3	77	8	Feb. 24	Feb. 26	2	70
3	Nov. 19	Nov. 23	4	75	9	Mar. 23	Mar. 25	2	72
4	Dec. 13	Dec. 18	5	70	10	Apr. 7	Apr. 9	2	75
5	Dec. 28	Jan. 1	4	68	11	June 6	June 8	2	76
6	Jan. 15	Jan. 18	3	63	12	July 14	July 16	2	79

THE SECOND NYMPHAL STAGE (THE DEUTONYMPH).

The second nymphal stage (fig. 3, *e*) is similar to the first nymphal stage except that it is much larger and more elongate. In its full-grown condition, however, it resembles more the adult, though the color is not as deep a red. It averages 0.38 mm. in length.

The habits of the second nymphal stage are likewise similar to those of the larva stage. The average length for the second nymphal stage is 2.84 days.

TABLE 4.—*Length of the second nymphal stadium.*

No.	Date emerged.	Date molted.	Duration.	Mean temperature.	No.	Date emerged.	Date molted.	Duration.	Mean temperature.
			<i>Days.</i>	<i>° F.</i>				<i>Days.</i>	<i>° F.</i>
1	Oct. 22	Oct. 25	3	76	7	Feb. 6	Feb. 10	4	65
2	Nov. 3	Nov. 6	3	77	8	Feb. 26	Feb. 29	3	70
3	Nov. 23	Nov. 25	2	75	9	Mar. 25	Mar. 28	3	72
4	Dec. 18	Dec. 21	3	70	10	Apr. 9	Apr. 12	3	75
5	Jan. 1	Jan. 4	3	68	11	June 8	June 10	2	76
6	Jan. 18	Jan. 24	3	63	12	July 16	July 18	2	79

BIOLOGICAL DATA.

Webbing.—Unlike the majority of red spiders this species does not spin an extensive web and carries on its depredations on the foliage practically unprotected. The only indications of any webbing made by this species are the mere fibrils attached to the apex of the eggs when deposited (fig. 3, *a*).

Average length of life period.—The length of the life period of the adult mites varies greatly with the season and temperature and possibly other conditions. Experiments on the life history of this species showed that adults emerging November 25 came to their natural death during the period January 1 to 15, while those emerging June 10 succumbed between July 1 and 15. This shows that during the dry winter months approximately two months are required from the time of emergence to the completion of the life period, while during the humid summer months approximately a month is required.

Molting process.—Before molting the mite securely attaches itself to the leaf. In emerging from the quiescent stage the old skin splits transversely along the cephalothoracic-abdominal suture. Following the splitting of the skin the anterior end of the mite is slowly drawn from the old skin. With the use of its fore legs the mite forces its way out from the shell.

Parthenogenesis.—Some immature individuals were isolated on a number of plants. From these individuals virgin females were obtained. These females produced eggs and in each instance the resultant individuals were males.

Migration.—There does not seem to be an alternate host of this species. Individual red spiders may be found on the avocado at any time during the year in varying numbers, and never leave the tree for want of a new or alternate host plant on which to feed. In a grove the red spiders are spread from tree to tree by the wind, birds, etc.

Generations of the species.—The generations of the avocado red spider fluctuate as to number and overlap considerably. In years of little rain during the fall the red spiders come in evidence more quickly than when rains occur earlier. Intermittent rains frequently

occurring during the red spider season also interfere with the regularity of the generations. Activity of the red spider usually commences during the latter part of August and ceases the first part of April, giving an active season of about 240 days. The average duration of the life cycle is 14.2 days, which would give 17 generations. This would be true where no interruptions due to climatic conditions occurred, and when no other factors interfered with the normal activities of the mites in the field.

Shedding of the foliage.—During the winter months the foliage may be termed “dormant,” no new growth being present on the trees. Usually during the latter part of March and April the avocado commences to bloom and the older leaves, which have served their purpose to the trees, commence to fall. With the shed leaves many mites are lost and do not regain positions on the trees. During the latter part

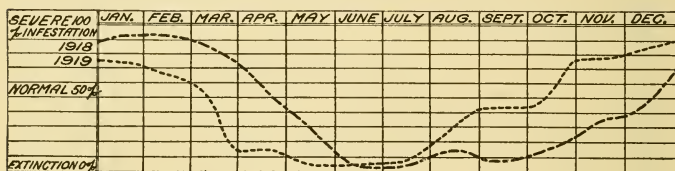


FIG. 4.—Curves showing 2-year composite seasonal status of the avocado red spider in southern Florida. The declinations arising through the amount of precipitation are the most important controlling factor in the activities of the species.

of April very little old foliage is present and a remarkable reduction of red spiders is apparent. A few old leaves, however, always remain on the trees until the newer growth has hardened and thus enable the red spiders to remain continuously on the trees and to infest the newer growth when it hardens.

Climatic control.—Climatic conditions existing in Florida influence the development and activity of the red spider to a marked degree. This particular species, as has already been stated, confines its depredations to the upper surface of the foliage. The species so working is exposed to the weather conditions. Hence during the period of the life cycle or seasonal cycle there is a series of fluctuations in numbers. In April, as the rainy season approaches, the red spider barely maintains existence. (Fig. 4.) During the months of June, July, and August no pronounced gain is made, but toward the latter part of October the avocado ceases to produce new growth, the red spiders commence to make their appearance in greater numbers, and increase during November and December. They usually reach the maximum number during January and February, and decrease again toward March. Precipitation is the one climatic factor important in reducing the red spiders during the spring and summer.

(Fig. 5.) During the summer in Florida drenching and frequent rains usually prevent the red spiders from establishing themselves on the trees. During late fall and winter and early spring it rains seldom, and the interference with the activities of the red spider is slight.

PREDATORY ENEMIES.

A number of predatory enemies of the avocado red spider aid at various times in keeping down the species on the avocado to a small degree.

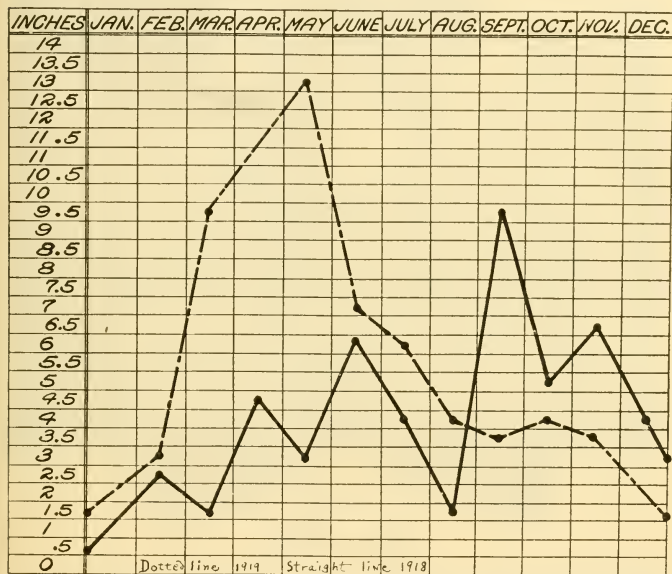


FIG. 5.—Precipitation chart for the years 1918 and 1919 in southern Florida.

Scolothrips seamaculatus Pergande is one of the predatory thrips and is not abundant during the height of the red-spider season. Nevertheless it is present doing its share of destruction. It is a light-colored thrips possessing six dark spots on its body. It feeds on the red spiders in both the larva and adult stages.

Chrysopa lateralis Guer. is one of the so-called lace-wing flies and is predatory in the larva stage on the red spider. The larvæ, while feeding and wandering about the foliage in search of their prey, carry with them a protection consisting of foreign material, such as cast red spider skins, etc. The larvæ have a voracious appetite and

possess powerful jaws with which they attack their prey. This species is quite beneficial.

Scymnus utilis Horn.—The most important enemy of the red spider found up to this time is a very small black ladybird beetle

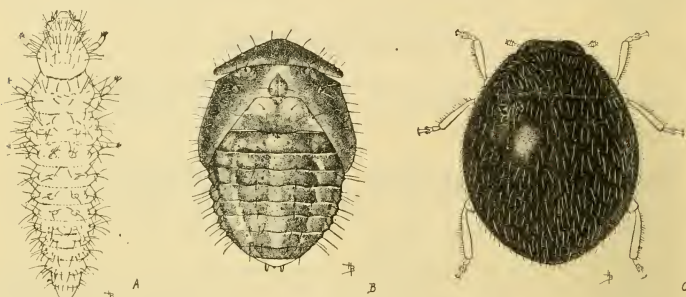


FIG. 6.—*Scymnus utilis*: a, Larva; b, pupa; c, adult. Greatly enlarged.

(fig. 6. c) about $\frac{1}{16}$ -inch long. With the beetles may be found their dark brown larvæ (fig. 6, a), also feeding on all stages of the red spider.

Scymnus kinzeli Casey is another ladybird beetle found feeding in both the larva and adult stages on the red spider. It is larger than

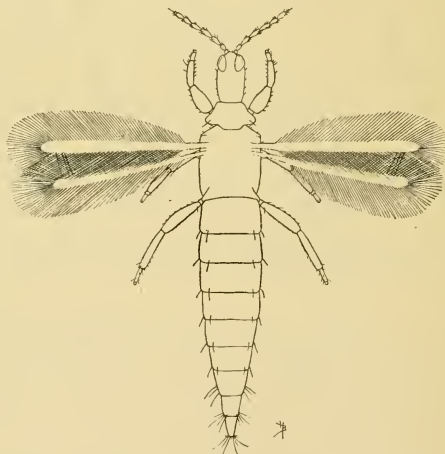


FIG. 7.—*Leptothrips mali*: Adult thrips. Greatly enlarged.

the former, the abdomen is black, and the head reddish. It is not a very abundant species and is not as beneficial as the former beetle.

Leptothrips mali Hinds is a large black thrips (fig. 7) predatory in both the larva and adult stages, and when present is very active

on the foliage in search of red spiders. It is not very abundant at any time.

SPRAYING EXPERIMENTS.

A number of insecticides have been tried out to ascertain their relative merits against the avocado red spider. The experiments were all conducted cooperatively with growers and in groves where the mite was abundant.



FIG. 8.—Power duster in operation using sulphur dust against the red spider in an avocado grove.

SULPHUR DUST.

An impalpable sulphur dust was tested on both the West Indian and Guatemalan races of avocados. In applying the material a power duster (fig. 8) was used. The sulphur proved to be very effective against the species, killing 99 per cent of the spiders, and remaining effective on the foliage over as long a period as did any of the liquid sprays tested. Experiments with this material showed that it was not necessary to apply the sulphur dust when the foliage was wet with dew. Where an avocado grower has a large acreage and the red spider is the only serious enemy to contend with, the dusting method is very practical and by far the quicker method. At the present time, however, the avocado grower has other insect pests with

which he has to contend, making it necessary to use liquid insecticides in combination with a sulphur spray in some form for their control. Up to this time the writer has not found it practical to use a combination of sulphur dust and 40 per cent nicotine sulphate against the insects of the avocado.

LIME-SULPHUR CONCENTRATE.

In using lime-sulphur concentrate spray on the avocado a number of strengths were tried, e. g., 1 gallon of concentrate to 40 gallons of water, 1 to 60, and 1 to 75. In spraying with lime-sulphur solution it was found through actual count that nothing is to be gained in applying too strong a solution of lime-sulphur to red spiders on the avocado. A strength of 1 gallon of the concentrate to 60 gallons of water proved to be the most efficient, generally killing 99 per cent of the spiders and producing sufficient body as a spray on the foliage to remain effective during the dry season against later hatching young. Under certain conditions applications of 1 to 40 and 1 to 60 were too strong, and considerable damage resulted to the foliage from burning, especially on the south side of the trees. When the temperature is above normal during the winter season, or when the trees do not attain a thoroughly dormant condition, a strength of 1 gallon of the concentrate to 75 gallons of water was found satisfactory. It was also ascertained that it is not necessary to incur the extra expense of adding a spreader of lime-sulphur spray, such as flour paste, glue, or fish-oil soap, because good results were obtained without it.

COMMERCIAL SODIUM SULPHID.

Commercial sodium sulphid was used at a strength of 2 pounds to 50 gallons of water. It was ascertained that this spray killed approximately 95 per cent of the red spiders present. Because of its chemical composition, however, the spray did not dry thoroughly on the foliage. The hygroscopic condition so formed permitted the spray covering the eggs and foliage to be readily washed off by succeeding rains, and nothing remained to destroy the hatching young.

NICOTINE SULPHATE CONTAINING 40 PER CENT NICOTINE.

At times the red spiders make their appearance during the fall before the fruit is picked. At this time it is not advisable to use any of the sulphur sprays, as they adhere to and discolor the fruit. By using 40 per cent nicotine sulphate at the rate of 1 part to 900 parts of water, with the addition of 2 or 3 pounds of fish-oil soap to each 100 gallons of the diluted spray as a spreader, satisfactory results were secured. The spray, however, proved to be effective only

temporarily, as none remained on the foliage to destroy the young on hatching.

SPRAY ROD VERSUS SPRAY GUN.

In making a comparison of the spray rod (fig. 9) and the spray gun (figs. 10 and 11) it was found that the latter gave better satisfaction against the red spider. Where an orchardist is short of help considerable benefit can be derived by using the spray gun, as the spray operator can cover the ground much faster than when using



FIG. 9.—Spraying in an avocado grove with spray rods.

the spray rod. As the red spider works on the top of the foliage the operator can stand off a short distance from the tree, and with the use of the spray gun can spray from the bottom to the top of the tree by turning the handle of the gun which changes the spray from the fan or fog spray (fig. 10) to a long-distance spray (fig. 11).

The writer has found that growers in using the spray gun often neglect to change the disk in the nozzle frequently enough and wonder why they can not maintain sufficient pressure while spraying. The operator should watch the opening of the disk in the nozzle of the gun, and should replace it when it is worn.

CULTURAL METHODS IN THE GROVE.

Clean culture does not play an important part in the control, as this species does not infest weeds or plants in or about avocado groves. Orchards mulched in various ways in southern Florida were found to be less infested with the red spider as a rule than those where clean culture was practiced. The avocado seems to thrive better where mulching is practiced and the moisture is conserved. Red spiders generally like dry conditions such as are afforded in



FIG. 10.—Spraying in an avocado grove with spray gun, using the fan or big fog spray.

groves where clean culture is followed. This is especially evidenced in seasons of drought during the year.

One factor which influences greatly the abundance and appearance of the red spider in a grove is the vitality of the trees. Nothing is to be gained by allowing trees to suffer from want of proper attention in the way of mulching, plant foods, and culture. Where growers are in doubt about the proper procedure to use in caring for their avocado trees, they should get in touch with either the Plant Introduction Garden maintained by the United States Bureau of Plant Industry at Miami, Fla., or their particular county agent.

RECOMMENDATIONS.

The presence of the avocado red spider on the trees in considerable numbers while the foliage is still green should be a sufficient indication of impending injury to cause the grower to begin immediate application of control measures. The grower should not wait until the foliage attacked becomes noticeably brown prematurely and begins to drop.

During the winter after the fruit has been picked use the liquid lime-sulphur 1 to 60. When the temperature is above the normal and the trees do not attain a thoroughly dormant condition the liquid lime-sulphur should be reduced to 1 to 75.



FIG. 11.—Spraying in an avocado grove with spray gun, using the long distance spray.

If the red spiders are present while the fruit is still unpicked in the fall, 40 per cent nicotine sulphate 1 to 900, with the addition of 2 or 3 pounds of fish-oil soap to each 100 gallons of the diluted spray, will give temporary relief and will not discolor the fruit.

Thorough application is a most essential point in combating the red spider.—If haphazard work is performed and much of the foliage left unsprayed, such infested foliage serves as a source of reinfestation to the tree, and the mites will be more in evidence after application than when thorough work has been done.

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BULLETIN No. 1040

Contribution from the Bureau of Entomology
L. O. HOWARD, Chief



Washington, D. C.

PROFESSIONAL PAPER

April 12, 1922

CONTROL OF THE CITROPHILUS MEALYBUG.¹

By R. S. WOGLUM,² *Entomologist*, and A. D. BORDEN,³ *Assistant Entomologist*,
Fruit Insect Investigations.

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INTRODUCTION.

In the fall of 1913 a mealybug infestation was noted on citrus at Upland, Calif., over an area of approximately 3 acres. At first it was assumed to be the common mealybug (*Pseudococcus citri* Risso), a species highly damaging in some citrus localities but never before reported in the Upland district. Growers were considerably alarmed over the discovery, knowing the severity of this pest and the ineffectiveness of control in other localities. Considerable damage was done to the infested groves in a hasty attempt at eradication by fumigation. At a convention held at Ontario, Calif., on January 30, 1914, the seriousness of the problem was discussed, although no real solution was evolved. A specific determination was made at this time by Essig⁴ as Baker's mealybug (*Pseudococcus maritimus* Ehrh.), a species then considered as of minor importance to citrus. In September, 1915, Clausen,⁵ after a brief investigation of the insect,

¹ *Pseudococcus gahani* Green; order Hemiptera, suborder Homoptera, family Coccidae.

² Resigned September 11, 1920.

³ Resigned December 5, 1921.

⁴ ESSIG, E. O. THE MEALY BUGS OF CALIFORNIA. *In* Calif. Mo. Bul., v. 3, no. 3, p. 110-111. 1914.

⁵ CLAUSEN, CURTIS P. MEALY BUGS OF CITRUS TREES. *Univ. of Calif., Bul.* 258, p. 30-35. 1915.

considered it a new species and gave it the name *P. citrophilus*. During the first four years various measures of control were tried by the growers and county and State officials without any marked success; in fact, the infested area continued to increase rapidly and the infestations became more severe.

The importance of this pest to the citrus industry and inability to control it led, in the summer of 1917, to a request for the United States Department of Agriculture to take up the problem, and the investigation was immediately started. Effective control methods were worked out in 1917 and 1918 and were generally employed throughout the infested area during 1919.

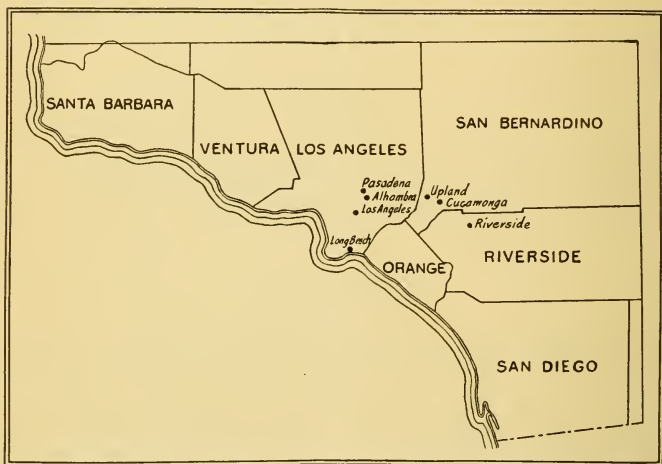


FIG. 1.—Present known distribution of the citrophilus mealybug (*Pseudococcus gahani*) in Southern California.

HISTORY AND DISTRIBUTION.

Definite records of the introduction of this mealybug into Southern California are lacking, but a study of its earliest occurrence and spread would indicate that it was brought in on some ornamental plants imported into Upland during 1910. The infestation of about 3 acres at the time of the first records (1913) had spread by the fall of 1915 to twice that area. By 1917 approximately 600 acres were infested, but since that time its spread has been greatly retarded by control means, though a few small infestations outside of the control area have been noted (fig. 1).

Shortly after the discovery of the Upland infestation the pest was found in Pasadena and has now become distributed over a consider-

able area in the northern part of the city. In 1916 over 100 acres of citrus were found to be infested at Riverside, and at the present time this infestation covers approximately 250 acres. Smaller infestations are recorded at Cucamonga and Alhambra on citrus. It is reported at Long Beach and Los Angeles on ornamentals and occurs in the northern part of the State in the San Francisco Bay region.

There is little probability of distribution by natural travel as the insect remains close to its host. The more important means of distribution are the picking boxes, picking sacks, clothing of the pickers and pruners, teams, wagons, and ladders; of slightly less importance is distribution by wind, birds, and insects. Several new infestations have been definitely traced to distribution through picking boxes previously used to transport infested fruit.

ECONOMIC IMPORTANCE.

In a severe infestation the mealybug not only masses on the twigs and foliage but also on the fruit. These masses may even cover from one-half to two-thirds of the surface and hang down in cottony festoons from the bud end. Such masses are common on severely infested lemons and on navel oranges, in the case of the latter particularly at the navel end. Where two fruits touch, a similar favored area of infestation is formed, especially on grapefruit and lemons. On young green fruit the immature forms crowd under the sepals, weakening the supporting tissues and influencing premature drop. The insects are also found in numbers on the young succulent new growth and sucker growth.

They secrete a honeydew which falls to the foliage or fruit below and in this medium grows a black fungus commonly known as "smut." The fruit and foliage become so black with this deposit as greatly to retard their development and to necessitate a special washing before the fruit can be packed.

The combination of the attack of the insects under the sepals and the deposit of "smut" frequently causes a heavy dropping of young, green fruit and also of the mature fruit, if held long on the trees. The deposit on the foliage results in a heavy leaf drop, often an almost complete defoliation of the tree. The feeding of the insects on the fruit destroys its natural gloss and often causes deep brown pittings in the rind which seriously affect the grading of the fruit. One packing-house manager reported a lowering of the grades from one severely infested orchard of from 30 to 40 per cent of the highest classed fruit. The lower grades are also seriously affected and frequently fall to culls, or unmarketable fruit. Severe infestations on lemons have been known to result in an almost complete loss of the crop, the fruit grading as culls.

HOST PLANTS.

The citrophilus mealybug is of importance commercially principally because of its infestation of citrus plants. The insect does occur, however, on a large number of other plants, principally orna-

mentals, upward of 30 different species being listed as hosts. On the citrus fruits it possibly shows its most rapid development on lemons, followed by grapefruit, navel oranges, and Valencia oranges, in the order given. It has been observed to develop very rapidly on the rhubarb, potato,

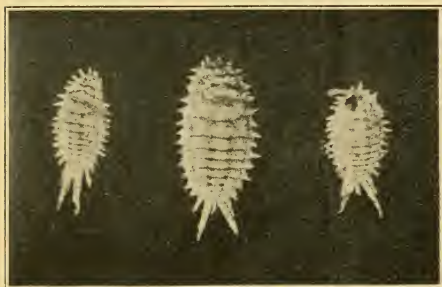


FIG. 2.—The citrophilus mealybug: Immature stages of the female.

grevillea, walnut, grape, and on species of *Coleus* and *Pittosporum*.

DESCRIPTION AND LIFE HISTORY.

The synonymy of the citrophilus mealybug was first correctly determined by G. F. Ferris in August of 1919.⁶ As stated, this insect was first confused with the common mealybug and later, by Essig, with Baker's mealybug. Clausen, in September, 1915, noted certain differences in him to describe it as characters which led a new species (*P. citrophilus*) but Ferris found that the same insect had been de-



FIG. 3.—The citrophilus mealybug: Mature stages of the female.

scribed by Mr. E. E. Green during May, 1915, as *P. gahani* from specimens taken from *Ribes sanguinea* in London, England. Un-

⁶ FERRIS, G. F. OBSERVATIONS ON SOME MEALY-BUGS (HEMIPTERA; COCCIDAE). In JOUR. ECON. ENT., v. 12, no. 4, p. 292-293. 1919.

fortunately the scientific name *citrophilus* had been adopted as the common name long before the correct determination was given.

The eggs are deposited in a flocculent mass behind the adult female and may number up to 1,000, though from 500 to 600 is the average. The period of incubation during the warm season is from 7 to 10 days.

Except in size, the larvæ are similar to the adult in appearance after the first molt and pass through three molts before reaching maturity. The characteristic arrangement of the wax is not strikingly noticeable until after the third molt. The immature stages of the female are illustrated in figure 2, the mature stages in figure 3.

The following description of the adult of *Pseudococcus gahani* is by Mr. E. E. Green:⁷

Adult female thickly coated with greyish-white mealy secretion, which is thinner in the folds of the segments and in the depressed areas. These depressions are in four more or less confluent longitudinal series which are more marked on the posterior half of the body. The darker color of the insect showing through the mealy covering at these spots, produces a distinct symmetrical pattern. There is a complete marginal series of 33 short conical waxy processes, an anterior and posterior pair being usually larger than the others. On each side of the anal orifice is a much longer, broadly laminate process which is transversely curved and spirally twisted, and between these is a pair of shorter processes, which together form a tube. Antenna, 8-jointed, the 8th longest; first joint strongly developed, approximately as long as it is broad; antennal formula (excluding 1st), 8 (3,2), (5,4,6,7), the last four being only approximately equal and varying slightly in their relative positions in the series. Limbs well developed; tarsus approximately half the length of the tibiae. Eyes prominent. Mentum distinctly biarticulate; longer than broad; terminal joint longest, acutely pointed. Dorsal glandular pits present but rather inconspicuous. Anal ring large and conspicuous, with six long stout setae. Anal lobes broadly rounded; only slightly prominent; more strongly chitinated than the surrounding parts, the margins of the chitinous area sharply defined; each with two stout conical spines, several fine hairs, some conspicuous circular pores, and a terminal seta which is approximately equal in length to those of the anal ring. Margins of segments, each with a small protuberance, bearing similar spines, pores and hairs, all of which become smaller and less conspicuous as they approach the anterior extremity. Derm with scattered, small, and inconspicuous pores. Many longish hairs on under-surface of head. Length, 2.50 to 3 mm. Breadth, 1.25 to 1.50 mm.

Adult male similar in appearance to that of *Ps. citri*. Length, 1.50 mm.

Though the structural characters agree somewhat closely with those of *citri*, the general appearance of the living insect is strikingly different, and it is of a much more active habit. * * *

Mr. Gahan observes that the insect, when irritated, exudes "a claret coloured liquid in round drops, two close to the head end and two at the tail end." The exudation evidently emanates from the glandular pits that are present in the positions indicated. He further remarks that the "dark-coloured secretion soon dries, looking like a small balloon. The liquid hardens into a solid substance which resembles lac or something of a similar nature."

⁷ GREEN, E. E. OBSERVATIONS ON BRITISH COCCIDAE IN 1914, WITH DESCRIPTIONS OF NEW SPECIES. *In* Ent. Mo. Mag., v. 51, p. 179-180. 1915.

SEASONAL HISTORY.

A most important feature in the biology of this insect was determined by observing the habits of the insect during the spring migration. The females, which during the winter have developed almost to maturity on the twigs, foliage, and fruit, migrate, in the spring, down the limbs to the trunk to oviposit. This migration usually begins during the early part of April and continues throughout the month of May. It is estimated that over 90 per cent of the insects take part in this movement, although not all have reached full development at this time. They settle on the rough places in the bark of the main limbs and trunk and soon begin ovipositing. On severely infested trees these accumulations of females with their cottony egg masses appear as large bunches of cotton hanging from the limbs and massed about the trunk and may be collected by handfuls. (Fig. 4.) These egg masses begin to hatch the latter part of May or early part of June, and the young larvæ start a migration back up the main limbs to the foliage and green fruit. The young settle along the midribs of young foliage, on the tenderest twigs, and under the sepals of the green fruit. Here they start feeding and their development is comparatively slow. By late fall many have become half grown and have settled in the more secure positions on the bud end or navel end of the fruit or between the fruit in clusters, and their development from then on is very irregular. During the winter many may have reached the oviposition stage, but the majority of the insects are still immature. There is a great reduction of numbers throughout the late fall and winter; in fact, on many trees it is often difficult to find them, but with the opening of spring the matured forms again enter into the migration. There is only one main generation a year, although the retarded development of some insects and the hastened development of others cause an overlapping of generations and consequently the presence of some insects in various stages of development at different times of the year. There is a possibility of an offhatch or overlapping of generations in the appearance of egg masses during the winter. This occurrence, however, is of minor importance in that the numbers of the mealybug are at their lowest at this time and most of the damage to the host has already occurred.

The young larvæ hatching from the egg masses in June are often killed by hot weather. In the summer of 1917 a very large percentage of the larvæ and eggs were destroyed by a short period of hot weather when the temperature exceeded 110° F. Again in the summer of 1918 the hatching occurred just before a warm spell and many larvæ were killed. That weather conditions and natural enemies are powerful factors in the control of this mealybug is very evident,

for only a small percentage of the larvæ hatching from the egg masses ever reach maturity. Many are washed off and destroyed by



FIG. 4.—Trunk of lemon tree showing masses of ovipositing females of the *Citrophilus* mealybug following the spring migration.

rain during the winter months and the development of others is greatly retarded during this cooler period.

RELATION TO ARGENTINE ANT.

In not a single instance has this mealybug become serious excepting where it has been attended by the Argentine ant (*Iridomyrmex humilis* Mayr). One case was noted in 1918 at Cucamonga where the mealybug had been observed for several years previous to that time, but never considered as doing any commercial damage. During the year 1918-19 the area became infested with Argentine ants and in the summer of 1919 control work on the mealybugs and ants became imperative. In every known locality where this mealybug now occurs it is attended by this particular ant.

COMPREHENSIVE DEMONSTRATIONS OF CONTROL.

EXPERIMENT NO. 1. DEMONSTRATION PLOT.

The orchard selected for demonstration of control methods at Upland in the summer of 1917 was near the center of the mealybug infestation (fig. 5) and was considered one of the worst infested groves, both as regards mealybugs and ants, in the colony. It consisted of two distinct plots of 10 acres each. The first 10 acres were planted to Valencia (6 acres) and navel (4 acres) oranges and had in all 674 trees. The second plot was planted largely to navel oranges (8 acres), with approximately 2 acres of old lemons, making a total of 676 trees. The trees were large and the lower limbs rested on the ground. A careful inspection of the Valencia fruit in August, 1917, showed an average of over 50 per cent of the fruit on each tree infested, with from 20 to 35 mealybugs to a fruit, besides the infestations on the foliage and sucker growth. Many of the trees carried from 90 to 100 per cent of infested fruit, with the foliage and new growth as severely infested. Practically every tree had a trail of ants and many were attended by two and even three trails. The infestation on navel oranges and lemons in the second 10-acre plot was as severe but showed only on the small green fruit and new growth.

ARGENTINE ANT ERADICATION.

Investigations, by the senior writer, of the common mealybug of citrus trees resulted in the discovery that this insect was effectively controlled by natural enemies, principally predators, in Argentine ant-infested territory provided the ants were eliminated. Therefore, when a survey showed that the citrophilus mealybug occurred exclusively in districts frequented by these ants, the first efforts were confined to a campaign against the ant in the hope that only such activity would be necessary, as had proved the case for the common mealybug.

The first operation undertaken was the trimming up of the branches from the ground so as to force the ants to ascend the trunks where the poison was placed. Two men trimming averaged 78 trees per day of 8 hours at a cost of approximately 8 cents per tree. The orchard was in a state of clean cultivation and entirely free of weeds beneath the trees.

Ant control was begun on about 1 acre of the first 10 in September, and the remainder completed by October 5, 1917. The second 10 was covered by ant control in November, 1917. An arsenical-sweetened sirup, known as the Barber formula, was used for the first distribution in this orchard, a small amount being placed in each container, one of which was attached to each tree. (Fig. 6.) Complete eradication was effected the following spring at a cost of 2.6 cents per tree on the first 10 acres and at a cost of 4.9 cents per tree on the second 10 acres. The control is summarized in Table 1.

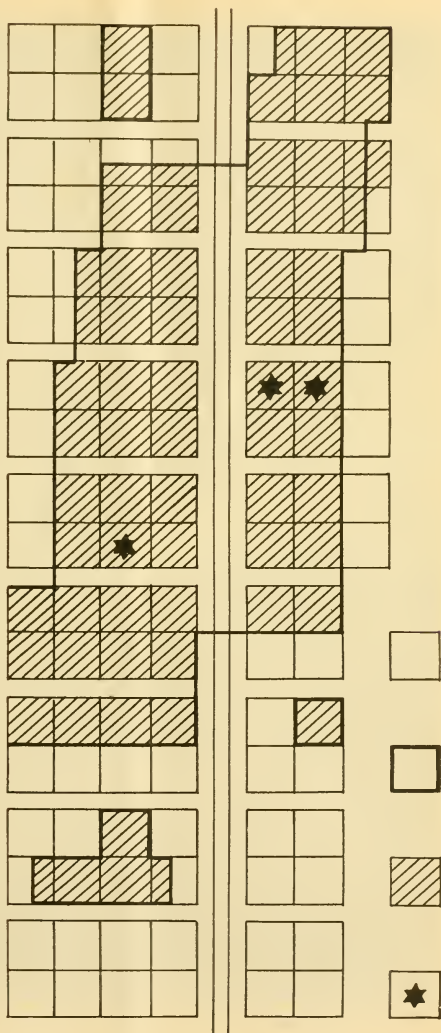


FIG. 5.—Citrophilus mealybug control areas, Upland district, 1917-1919.



FIG. 6.—Tree trunk showing burlap band and ant poisoned-sirup can in position.

TABLE 1.—Control of the Argentine ant in a citrus orchard at Upland, Calif., 1917.

DEMONSTRATION PLOT, FIRST 10 ACRES, 674 TREES.

Date of inspection.	Poison distributed.	Trees with ants.					Check area.				
		Clean.	Very light trail.	Light trail.	Medium trail.	Heavy trail.	Clean.	Very light.	Light.	Medium.	Heavy.
Sept. 23.		5	99	312	133	125					
	Oct. 5		Over entire area.								
Mar. 24.		671		3							
	Apr. 9		Only on trees with ants.								
Apr. 9.		648	20	6							
	June 17		Only on trees with ants.								
June 17.		642	17	15							
June 29.		672	2								

DEMONSTRATION PLOT, SECOND 10 ACRES, 676 TREES.

Sept. 23.		2	157	266	107	68		9	23	20	24
	Nov. 5		On 600 trees.					Trap nest under 76 trees.			
Mar. 20.		391	119	61	15	14	8		19	23	26
	Apr. 1		On 600 trees.								
	Apr. 5							On 76 trees.			
Apr. 30.		546	39	10	4	1	57	13	5	1	0
June 11.		577	18	5	0	0	75	1	0	0	0
June 29.		593	7	0	0	0	76	0	0	0	0

BURLAP BANDING.

Although by winter the ants were controlled and early the following spring were almost completely eradicated, the mealybugs continued in severe infestations and during the latter part of March were noted to begin descending the tree trunks. The descent continued to increase in April and no large number of natural enemies appeared as was anticipated. It soon appeared that elimination of the ant was not alone sufficient to bring about control of the citrophilus mealybug, as had proved the case for the common mealybug. The citrophilus mealybug species was not attacked by either numerous or effective natural enemies. The necessity of artificial means of control to supplement ant eradication was thus at once apparent.

A study of the habits of this mealybug showed a spring migration to the trunk and rough places on the main branches where egg masses for the succeeding generation are deposited. The accumulation of insects and egg masses in cases of severe infestations, as previously pointed out, became so great as frequently to present the appearance of large tufts of cotton. This massing on the trunk and lower branches presented a favorable point of attack and the spraying of these masses with an effective insecticide promised a great reduction of the total insects present. It was noted, in the case of some trees which had been banded with cotton bands by an orchardist at Upland in 1915, that these acted to attract the ovipositing females beneath them in great masses. Since cotton bands were scattered by the winds and birds, it was decided to substitute burlap and ac-



FIG. 7.—Trunk of lemon tree with burlap band removed showing masses of ovipositing females of the citrophilus mealybug collected under band.

cordingly in the spring of 1918 the trees in the demonstration orchard were thus banded. (Fig. 6.) A band of burlap about 6 inches wide was wound around the trunk just below the main branches and caught at each end with a finishing nail. The migrating females

readily collected under the bands preparatory to oviposition. (Fig. 7.)

The success of burlap bands as used on the demonstration plot led the growers throughout the infested area to adopt the practice. This necessitated a large supply of burlap bands and the problem was solved by buying the burlap of 30-inch width in bolts of about 100 yards. The bolts were cut at a printing office under a large paper knife into six rolls, 5 inches in width, which could readily be carried into the orchard and cut in appropriate lengths for individual trees. The ends of each band were fastened over a 4d finishing nail driven into the trunk of the tree. The average orchard of 900 trees was banded with one full bolt of burlap. The average cost in 1919 was as follows:

1 roll burlap (100 yards)-----	\$12. 60
Cutting-----	1. 00
Nails-----	. 15
Labor (1 man, 1 day)-----	3. 00
	16. 75

Cost per tree, approximately \$0.02.

During April and May insects continued to descend in great numbers, the burlap bands proving a center of attraction. In cases of light infestation the majority of the descending insects would settle beneath the band, and this was particularly true on smooth-barked orange trees. (Fig. 8.) Lemon trees with the more irregular trunks and depressions where the main branches join the trunks offered favored places for the mealybugs to settle, although even these seemed less favored by them than the bands. By the latter part of May hatching started, following which the larvæ migrated back to the foliage and fruit on the tree. Before this happened the bands were removed and dipped in an effective insecticide, usually pure petroleum distillate, and the trunks were then sprayed.

SPRAYING.

Spraying operations on the first 10 acres were conducted on May 23 and 24, and on June 6 and 7 on the second 10 acres. Only the main limbs and trunks were sprayed and for this a petroleum distillate-soap emulsion applied with a power sprayer at 150 pounds pressure proved most satisfactory. Two leads of hose with angled Bordeaux nozzles were used. The burlap bands were removed and thoroughly sprayed as the trunks were being sprayed. The formula used was as follows:

Distillate 28° to 30° B-----	gallons--	10
Soap powder-----	pounds--	20
Water to make-----	gallons--	200

If a lighter oil, as stove distillate, is used, the amount should be increased to 15 gallons. A good agitator is necessary in mixing the spray. After a few

inches of water are in the bottom of the tank, the soap powder is sifted in as the tank is being filled and the agitator is running. The oil is added last before the tank is full.



FIG. 8.—Three burlap bands from the trunks of orange trees following spring migration of the *citrophilus* mealybug.

It was felt that the spraying of the bands was not entirely satisfactory unless the greatest care was used, so in subsequent work it was decided to dip them just before spraying. The application, to

be effective, must be thorough and to accomplish this it is necessary to go beneath the tree. The most satisfactory work was done when the nozzle was connected directly to the hose, allowing free manipulation in any direction. A long rod should never be used as it does not allow the ready manipulation necessary on heavily branched trees to spray from any direction.

The trees on the demonstration plot were of an open type with smooth trunks and high headed, so they could be entered with ease and quickly and thoroughly covered with spray. It required only $3\frac{1}{2}$ tanks of spray to cover each of the 10 acres. The cost (1918) is summarized herewith:

35 gallons distillate, at \$0.05 per gallon.....	\$1.75
70 pounds soap powder, at \$0.05 per pound.....	3.50
Team and teamster for $1\frac{1}{2}$ days.....	9.00
Two men spraying for $1\frac{1}{2}$ days.....	9.00
Gasoline and oil.....	1.25
Total.....	24.50

Cost per tree, \$0.036.

The time, $1\frac{1}{2}$ days, included considerable engine trouble. Fifty-two trees were sprayed in 30 minutes. A tank of spray (200 gallons) covered approximately 200 trees.

Several days after the spraying the burlap bands, now dry, were replaced on the tree trunks and left for a year. At no time were insects noted under the bands except an occasional one, which the natural enemies destroyed before oviposition was completed.

Throughout the following fall and winter (1918-19) it was very difficult to find even individual mealybugs, and the packing house handling the fruit reported it to be cleaner than any that had been turned in during the five preceding years, with an increase of grade amounting to from 30 to 40 per cent.

During the spring of 1919 an inspection was made of the demonstration plot and very few mealybugs and no ants were found. Under the old bands not more than 10 to 12 insects were found on any one tree. The grove was sprayed again by the owner in June of 1919, as outlined above. An inspection in May, 1920, showed a practically clean grove, not more than 5 insects being found under the bands of any tree, and most of the trees were entirely free of mealybugs.

EXPERIMENT NO. 2. FARLOW GROVE, 888 TREES.

In the summer of 1919 a second demonstration plot was employed which consisted of 10 acres of heavily infested oranges. Ant control and banding had been carried on the previous spring, and the ants were greatly reduced at the time of spraying. In this grove, as in the former, a power sprayer with two leads of hose and Bordeaux

nozzles were used. Distillate-soap powder emulsion, soap powder, and water were used, as shown in Table 2, and data were gathered on the efficiency of the different solutions.

Before the spraying started a man was sent through to remove the heavily infested bands, dip them in pure distillate, wring them out, and place them to one side to dry.

TABLE 2.—*Summary of spray operations against the citrophilus mealybug.*

Spray.	Total number of trees sprayed.	Average number of trees per tank.	Average spray time per tank.	Average number of gallons per tree.	Effective-ness of spray.
5 per cent distillate-soap powder emulsion.....	777	59	<i>Min.</i> 58	3.4	Excellent.
Water.....	69	34	85	5.7	Poor.
40 pounds soap to 200 gallons water.....	42	42	45	4.8	Do.

Both the water and soap-powder treatments were discontinued, as it was found to be impractical in application to get a thorough clean-up of the egg masses. The distillate-soap emulsion was quicker in application and more effective.

The bands were replaced shortly after the completion of the spray work, and field observations made from time to time throughout the following year. Though some mealybugs appeared under the bands following the spraying, they were completely controlled by natural enemies and required no further treatment. Throughout the fall and winter no mealybugs were apparent, and in the spring of 1920 so few mealybugs appeared under the bands that hand treatment was all that was required. The grove is now commercially clean, and there has been a marked increase in the grade of the fruit.

The data obtained in this experiment not only demonstrated the practicability and efficiency of the distillate-soap emulsion but also demonstrated the advisability of proper pruning before spraying. The trees on this grove were low on the ground and it was difficult to treat the trunks owing to low branching and inside growth. In consequence of this condition it took much more material and a longer time to make the application. The cost of spraying was as follows:

Removing and dipping bands, 1 man, 1 day.....	\$3.00
16½ tanks spray:	
330 pounds soap powder, at \$0.07 per pound.....	23.10
165 gallons distillate, at \$0.07 per gallon.....	11.55
Two men, at \$4 per day, 2 days.....	16.00
Team, at \$4 per day, 2 days.....	8.00
Gasoline and oil, 2 days.....	2.50
Total.....	64.15

Cost of \$0.072 per tree.

HAND-TREATMENT METHOD.

In a 5-acre citrus orchard, comparatively lightly infested with mealybugs and banded early in the spring of 1919, the hand-treatment method was effectively employed. This consisted of removing the bands and dipping them in a bucket of 25 per cent distillate-soap emulsion, wringing the bands out dry, scrubbing the trunks with a suitable brush, and replacing the bands.

Different strengths of the emulsion were tried with results as shown in Table 3.

TABLE 3.—Results of hand-treatment method against the *citrophilus mealybug*.

Strength of solution.	Effectiveness—	
	On adults.	On egg masses.
5 per cent.....	Poor killing.....	No effect.
10 per cent.....	50 per cent killing.....	Poor.
25 per cent.....	100 per cent killing.....	Excellent.

The 25 per cent solution is prepared as follows:

Place 6 quarts of water in a bucket and thoroughly dissolve $\frac{1}{2}$ pound of soap powder. To this slowly add 2 quarts (30° Baumé) distillate while constantly stirring. Attach the bucket pump and pump the solution back into the bucket through a mist nozzle until a perfect emulsion, free of oil globules, is obtained. The emulsion should be used soon after preparation.

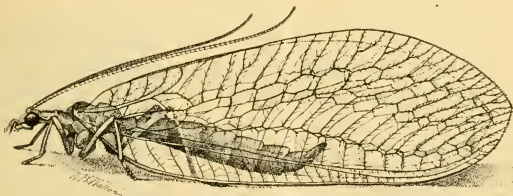


FIG. 9.—Adult of *Chrysopa californica*. Much enlarged.

Several growers have used this method successfully on light infestations, where followed up at intervals of about every two weeks from the middle of May to the latter part of June, at a cost of 2 cents per tree for each treatment. It is as important to effect ant eradication when this method is employed as it is with the regular trunk-spray method.

CONTROL WORK—UPLAND DISTRICT, 1919.

The great success of the demonstration work of 1917 and 1918 led to the general adoption of the control methods by the growers throughout the infested area. (Fig. 5.) Up to and including 1919 ant control was practiced on 630 acres. The entire mealybug-infested

acreage was banded with burlap in the spring of 1919. Of the area infested with the mealybug in that section all but 10 acres were sprayed according to the methods outlined, with excellent results throughout. The 10-acre orchard was left as a check for control by natural enemies.

The ant control was handled partly by the growers themselves, partly by the citrus associations of which the orchardists were mem-

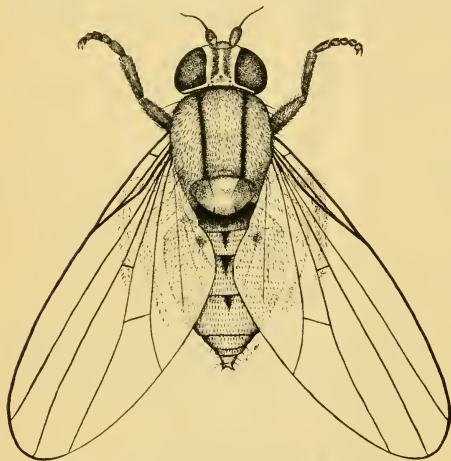


FIG. 10.—Adult of *Leucopis bella*. Greatly enlarged.

bers, and partly by contract operators. The sirup was for the most part prepared by the citrus associations, or purchased from druggists at a cost of \$1.50 to \$2 a gallon. The spice tin was the preferred container. The average cost to the grower for ant control, including refilling where necessary, was 4 to 6 cents per tree. The cost of burlap banding averaged 2 cents per tree. The cost of trunk spraying varied. On dense, unpruned lemon trees, headed low, spraying proved somewhat difficult and slow. The amount of material used on such trees was also greatest. High-headed orange trees with smooth trunks were most easily and effectively sprayed.

These spray operations were conducted by the growers and commercial outfits and an average of 10 acres a day was covered at a cost approximating the figures given for the two demonstration plots, the cost being more or less proportional to whether the trees were well pruned and open or unpruned and difficult to spray. Work carried out by the owners themselves was for the most part thoroughly done. A few orchards were trunk-treated by hand.

The general results of the control campaign of 1919 at Upland were very gratifying. Orchards which had shown severe infestations in the spring of 1919 were commercially clean in the spring of 1920. The reduction in grade or total loss of fruit from mealybugs had been reduced to a negligible factor. Packing-house managers and growers were convinced that the citrophilus mealybug was no longer a menace to their orchards and that the control of

members, and partly by contract operators. The sirup was for the most part prepared by the citrus associations, or purchased from druggists at a cost of \$1.50 to \$2 a gallon. The spice tin was the preferred container. The average cost to the grower for ant control, including refilling where necessary, was 4 to 6 cents per tree. The cost of burlap banding averaged 2 cents

this insect was on such an effective commercial basis that timely future attention would effectively hold it in check.

NATURAL ENEMIES.

Though the ant control, banding, and trunk spraying have given excellent control of the citrophilus mealybug, the importance of its natural enemies in conjunction with this artificial means of control needs emphasis. The natural enemies are very effective against light infestations, if the ants are not present, and even in heavier infestations are important in assisting to destroy the insects on the foliage and trunks following spray treatment. The most effective natural enemies present in the groves are all predators and appear to rank in order of importance as follows: *Chrysopa* spp. (fig. 9), *Leucopis bella* Loew (fig. 10), and *Scymnus sordidus* Horn



FIG. 11.—Adult of *Scymnus sordidus*. Greatly enlarged.



FIG. 12.—Larva of *Cryptolaemus montrouzieri*. Much enlarged.

(fig. 11). They breed freely in the cottony mass of ovipositing females on the trunks, although by no means noticeably reducing the mealybug on heavily infested trees. It is, however, following the migration of the mealybug larvæ to the tender fruit and foliage that the effectiveness of these natural predators is most felt. Here they search out and destroy the young mealybugs, and in the case of light infestations frequently prevent the development increasing to severe proportions. *Chrysopa* and *Leucopis* are usually most numerous during the late spring and summer, while *Scymnus* is most effective during the early fall.

The natural predators of primary importance in controlling the common mealybug, namely, *Sympherobius* spp. and *Hyperaspis lateralis* Muls., are of very secondary value against the citrophilus mealybug. *Cryptolaemus montrouzieri* Muls. (figs. 12, 13), however, is very effective against either species. This predator was first tried against the citrophilus species by the writers at Alhambra during

1916 and proved so effective that several hundred were distributed beneath a tented citrus tree at Upland during the autumn of 1917. Some specimens successfully passed the winter and started breeding freely the following spring. The Insectary Branch of the California State Commission of Horticulture followed the writers' lead and has since distributed many thousands over the Upland district, with such successful returns that the work should be supported and continued.

SUMMARY.

(1) Ant control. This is most effectively accomplished by the use of a special arsenical poisoned sirup in small containers, one to each tree. Best results follow distribution during the autumn or spring.

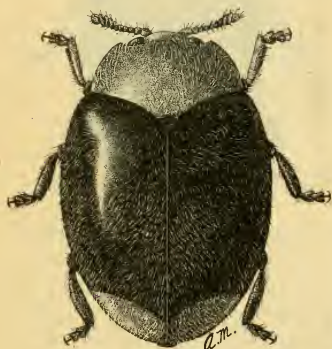


FIG. 13.—Adult of *Cryptolaemus montrouzieri*. Much enlarged.

(2) Trunk banding. Strips of burlap about 5 inches wide should be placed around each tree trunk, from February to April, to attract ovipositing female mealybugs.

(3) Removal and dipping of burlap bands in distillate. This should precede the trunk spraying. The bands should be dry when replaced after the trunk treatment.

(4) Trunk treatment. Spray thoroughly with distillate-soap powder emulsion after the mealybugs have massed on the trunks and just before the eggs begin to hatch. This is usually during the latter part of May.

(5) The propagation and distribution of *Cryptolaemus montrouzieri*, *Leucopis bella*, *Chrysopa* spp., and *Scymnus sordidus* are to be recommended.

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L. O. HOWARD, Chief

And the Bureau of Plant Industry

WILLIAM A. TAYLOR, Chief



Washington, D. C.



April 13, 1922

RED CEDAR CHESTS AS PROTECTORS AGAINST MOTH DAMAGE.

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INTRODUCTORY.

Chests made of red cedar have the reputation of protecting clothing stored in them from the ravages of clothes moths. There has been, however, much difference of opinion as to whether the supposed protection comes from the tightness of the chests which excludes moths, or from an inherent quality of the wood that actually kills moths accidentally placed in them with fabrics and furs. Considering the centuries-old belief, entertained among so many peoples, that this odoriferous cedar affords protection against moth attack, surprisingly little has been done to determine whether or not chests made of this wood are efficacious. Working with the southern or webbing clothes moth, *Tineola biselliella* Hummel (Pl. II, A), the writers undertook a comprehensive study of the effect of red cedar chests upon adults, eggs, and larvæ to ascertain whether or not chests made of red cedar could be considered as adequate protection of clothing against these insects.

SOURCE, DISTRIBUTION, AND DESCRIPTION OF RED CEDAR.

Red cedar (*Juniperus virginiana*), commonly known as Tennessee or Virginia red cedar, is one of the most widely distributed coniferous trees of North America, occurring on dry hills or in deep swamps, sometimes attaining a height of 90 feet, but usually averaging 40 to 50 feet or less. The tree is distributed throughout all sections of the United States as far west as the Rocky Mountains, flourishing under various climatic conditions. It is most abundant, however, in the region from the Ohio River on the north to Florida on the south and from the Atlantic Ocean on the east to Arkansas on the west. In Tennessee, Virginia, and North Carolina the red cedar occurs in large areas of nearly pure forests known as "cedar breaks." In these sections the most extensive manufacture of cedar lumber is conducted.

In general, the red cedar is a straight tree, pyramidal in shape becoming round-topped in old age, and has a tapering trunk and shreddy bark. The wood is light, close-grained, compact, and durable. The heartwood is red in color and strongly aromatic, while the sapwood is white and devoid of odor.

USES OF RED CEDAR.

The commercial use of the wood dates back to the seventeenth century. In 1632 Morton (12, p. 49-54, pl. 45),¹ in citing the trees that are found in New England, stated:

Cedar, of this sorte there is abundaunce; and this wood was such as Salomon used for the building of that glorious Temple at Hierusalem. . . . This wood cutts red, and is good for bedsteads tables and chests, and may be placed in the Catalogue of Commodities.

In 1682 Gent (4, p. 63), in describing the resources of South Carolina, mentioned the presence in that State of odoriferous and fragrant woods, among them being the sweet-scented cedar and cypress, from both of which were made boxes, chests, tables, and cabinets. He further stated that:

The Dust and Shavings of Cedar, laid amongst Linnen or Woollen, destroys the Moth and all Verminous Insects; It never rots, breeding no worm, by which many other Woods are consumed and destroyed.

In 1757 Peter Kalm (7, p. 264), in a report of his early travels in North America, mentioned red cedar as being prized for its durability.

In 1776 Hunter (6) stated that the timber was very valuable for many uses and possessed a bitter resin which prevented worms from attacking it. Later, in 1786, Lamarck (9) stated that the wood was much sought in America for carpentry, construction of vessels, woodwork, and different utensils, because it was filled with a bitter resin which prevented its destruction by worms. According to Bigelow (1, p. 49-54, pl. 45), in 1820, the wood—

is principally employed for posts in fences, in which capacity it proves more durable than almost any species of wood used for the same purpose.

London (10, p. 848), mentioned *Juniperus virginiana* as producing lumber which is "very odoriferous" and useful for cabinet making

¹ The figures (*italic*) in parentheses refer to "Literature cited," p. 14.

"as it is offensive to most insects." In 1838 he stated (11) that on account of its strength and durability the barriers of the sidewalks of the streets of Philadelphia were made of this wood, which was also used for making tubs, stopcocks, and coffins.

In presenting certain historical data of New York, O'Callaghan (13, p. 40), in all probability referring to red cedar, stated:

There is Red-wood which being burned, smells very agreeable; when men sit by the fire on benches made from it, the whole house is perfumed by it.

Porcher (14, p. 588-589), in 1869, made the statement that—

Cedar boxes are not infested by insects, moths, etc., and are used for storing away woollens. The leaves also prevent the attacks of insects when spread over cloth.

Further reference to the use of red cedar against insects was made by Emerson (3, p. 120) in 1875, to the effect that the agreeable and permanent odor of the wood recommends it for certain uses, such as pencils and the bottoms of boxes and drawers, the aroma making it a safeguard against insects. Similarly, it was stated by Curtis (2, p. 118-119) that boxes and cabinets made of red cedar wood were exempt from insects on account of its odor being offensive to them. Hansen (5, p. 298-299) stated that the wood possessed much economic value, being durable and free from the attacks of insects.

It was reported by Sargent (15) in 1895 that the wood of red cedar is highly resistant to decay and that insects do not molest it. It is further stated by the same author that moths flee from the pungent odor, and that every good housekeeper knows the value of a red cedar chest or a closet lined with this wood. The following year (16) he also asserted that the wood is very fragrant and easily worked, being used largely for fence posts, railway ties, sills, cabinets, lead pencils, the interior finish of houses, and for protecting woollens against the attack of moths.

According to Kent (8) the wood is highly resistant to decay by water and is therefore valuable for fence posts and other purposes where it comes into contact with moist soil or water. This author also states that moths flee from the pungent odor, and that a chest of red cedar or a closet lined with red cedar wood affords an efficient protection against their inroads. It is also reported that the waste at pencil factories is used to manufacture a paper which has been found useful for wrapping wools, furs, and other articles likely to be injured by moths.

It is stated by White (18) that the heartwood of the cedar constitutes the portion of the tree which is used extensively for pencil making. For this purpose it is essential to have the straight-grained red wood, free from knots.

On account of the lack of cedar logs of any great size and the need for the heartwood free from knots, old logs and fence rails are being used for the manufacture of pencil slats.

Within the last 15 years red cedar has been used in constantly increasing quantities in the manufacture of cedar chests. All of the red heartwood and part of the white sapwood is utilized for this purpose. The industry has grown very rapidly and at the present time red cedar chests are recognized as staple articles of furniture. These chests combine ornamental beauty with utility as receptacles for the storage of clothing. Their beautiful and attractive appear-

ance is due to the striations of red heartwood and white sapwood interspersed with the deeper-colored circular or oval knots. By means of the firm construction, the extremely tight-fitting cover, and the heavily-varnished exterior, the odor of the wood is retained within the chest. In this connection it may be of interest to state that during a recent pilgrimage to "The Hermitage," the plantation of Andrew Jackson, located near Nashville, Tenn., in the heart of the red cedar belt, there was seen a hand-made cedar chest which was considerably over a hundred years old. It is reported that this chest still retains the full fragrance or aroma of the cedar, and doubtless from the standpoint of odor still possesses its original efficiency.

AROMA OF RED CEDAR.

The persistent, characteristic odor of red cedar, which has been credited with possessing the property of destroying the clothes moth, or at least preventing damage by it, is due to a volatile oil which forms 1 to 2 per cent of the wood. The pure heartwood, or the red wood, contains from 2 to 4 per cent of this volatile oil, which is pale yellowish-brown in color and possesses an agreeable, persistent odor. The principal constituents of the oil are the alcohol cedrol, or cedrol camphor, which can be separated from the oil in the form of crystals; the sesquiterpene alcohol cedrenol; and the sesquiterpene cedrene. The characteristic odor is probably due to the former two compounds. It is stated that the oil possesses antiseptic properties, but little is known regarding its insecticidal properties.

CEDAR CHEST EXPERIMENTS.

The only experimental work previously recorded was by Scott, Abbott, and Dudley, reported (17) upon in 1918. These authors, working with the southern, or webbing, clothes moth (*Tineola biselliella*) and one cedar chest, the history of which was not known, concluded that a red cedar chest killed adults and newly hatched larvæ, but had no effect on larvæ half grown or larger. With these conclusions the writers, working also with *Tineola biselliella*, agree in the main, although none of the chests used by them in their work either killed adult moths or prevented them from laying eggs.

In the experimental work recorded below, nine red cedar chests, with a capacity of from 3.9 to 5.5 cubic feet, were obtained newly made in 1920 from representative manufacturers. These chests (Pl. I) were from regular stock and were shipped direct from the factory. They were of $\frac{3}{4}$ -inch lumber, had the usual attractive finish, and were of the average run of chests placed upon the retail market.

EFFECT UPON ADULT MOTHS.

Scott, Abbott, and Dudley state (17) that 70 adult moths were introduced into a cedar chest and that an examination two months after the last adults were introduced showed that "all had been killed and that no eggs or larvæ were present." This conclusion regarding the effect of a cedar chest upon adult life is not justified since in longevity experiments on file adult clothes moths have never lived two months and seldom so long as 30 days. The same authors state also that 30 adults and a supply of flannel were added to the same chest two years later. Observations made nine weeks after the



NINE CEDAR CHESTS, RANGING IN CAPACITY FROM 3.9 CUBIC FEET TO 5.5 CUBIC FEET, USED IN EXPERIMENTAL WORK.

experiment was started revealed no living adults, no eggs, and no larvæ. In a trunk serving as a check to which the same number of adults were added at the same time, more than 50 live larvæ were counted on the flannel at the close of the experiment. This is the only reference in literature to the effect of cedar chests upon adult clothes moths.

The following data indicate that the cedar chests used by the writers have little practical effect upon the length of life or upon the egg-laying of adult moths. The data are incomplete, but sufficient to prove that adults developing in chests from larvæ transforming to the pupa stage in the chests can live at least 10 days, which in longevity experiments conducted as checks was about the average length of life under normal conditions. It is possible, moreover, for such adults to mate and deposit eggs that will hatch.

On June 17, 1920, 15 adults (sex undetermined) newly emerged in chests were placed with cloth in Chest 1. On June 26, 11 were alive and eggs had been laid. On June 28 all adults were dead, and 123 eggs had been laid; by July 6 all eggs had hatched. Twenty larvæ removed from the chests on June 28 continued to develop normally outside the chest.

On July 2, 1920, 7 adults (sex undetermined) emerging in the laboratory were introduced with cloth into Chest 2. Adults were found depositing eggs on July 3. Examination on July 17 showed 18 eggs had been deposited, 14 having hatched. One adult was barely alive, being too feeble to crawl.

On March 28, 1921, one group of three virgin moths and another group of five, emerging within cedar chests, were placed with cloth in Chest 1. Examination on May 31, 1921, showed all adults dead, and 53 and 30 eggs deposited, respectively. These eggs were infertile and did not hatch.

On March 30, 1921, 6 adults (sex undetermined) found emerged in cedar chests were placed the same day in Chest 2, with cloth. Examination on April 28 showed 1 adult alive, about 80 eggs laid and hatched, and living and dead larvæ.

EFFECT UPON EGGS.

Cedar chests have no apparent effect upon clothes-moth eggs. This is true of eggs deposited in the chests by females emerging in the chests or by females emerging in the laboratory and placed in the chests for oviposition, and of eggs laid outside of chests and later introduced into them. Scott, Abbott, and Dudley (17) state that an examination of a piece of flannel containing many clothes-moth eggs 23 days after it was placed in a cedar chest showed that practically all the eggs were hatched but that the resulting larvæ had died almost immediately. A duplicate test by them gave identical results.

On June 5 and 18, and July 10, 1920, and February 12, March 3, 10, and 28, April 27, May 7 and 14, and June 6, 1921, an average of about 300 eggs, ranging in age from 1 to 7 days, were introduced into each of four cedar chests. Of 50 experiments conducted to determine the effect of chests upon the egg vitality the following 10 are recorded as typical:

(1) Twenty-six adults (sex undetermined) were found March 28, 1921, having developed in cedar chests from larvæ introduced into

the chests January 21, 1921. The adults were placed in a large vial with cloth and immediately replaced in Chest No. 1. Examination May 11 proved that about 200 eggs had been deposited and practically all eggs had hatched.

(2) Four adults (sex undetermined) found in chests April 8, 1921, developed from larvæ introduced into the chests January 1, 1921, were placed with cloth in the chests. Examination April 30 determined that 43 eggs had been deposited and all of them had hatched.

(3) On February 12, 1921, 24, 30, 22, and 14 eggs, deposited, respectively, on February 9-12, 10-12, 11-12, and 12, were placed in Chest 2. Examination on March 2 determined all eggs to have hatched.

(4) On March 10, 1921, 54, 106, 52, 25, and 45 eggs, deposited, respectively, on March 3-5, 5-7, 7-8, 8-9, and 9-10, were placed in Chest 2. Examination on March 17 determined that all eggs had hatched except 46, and of these, 40 were those deposited on March 9-10. Of 292 eggs deposited March 12-14 and held as checks in the laboratory outside of chests, 148 hatched on March 21-22 and 144 on March 22-23. A second examination on March 30 determined all eggs hatched. Of 32 eggs deposited March 2-3 and held as checks in laboratory outside chests, 20 hatched on March 14 (no further observation made).

(5) On April 27, 1921, 232 and 102 eggs deposited April 24-27 and April 26-27, respectively, were placed in Chest 1. Examination on May 11 determined that all eggs had hatched. Of 284 eggs deposited on April 24-27 and held in the laboratory outside of the chests, 100 hatched April 30 and 184 between April 30 and May 3.

(6) On May 14, 1921, 160, 53, 75, 69, 38, and 94 eggs deposited on May 7-9, 9-10, 10-11, 11-12, 12-13, and 13-14, were placed in Chest 3. Examination on May 19 determined that eggs deposited on May 7-11 had hatched; those deposited on May 10-11 were just hatching and the larvæ had not yet had an opportunity to feed. The 69, 38, and 94 eggs deposited between May 11 and 14 were not hatched but were found hatched when examined May 31. Of 336 eggs deposited May 5-6, 1921, and held as checks in the laboratory outside of chests, 111 hatched May 13, 146 on May 14, and 79 on May 18.

(7) On June 6, 1921, 28, 51, 32, 12, and 91 eggs deposited, respectively, on June 1-2, 2-3, 3-4, 4-5, and 5-6, were placed in Chest No. 1. Examination on July 7 determined that all eggs had hatched.

(8) On May 14, 1921, 138, 60, 61, 43, 36, and 19 deposited, respectively, on May 7-9, 9-10, 10-11, 11-12, 12-13, and 13-14, were introduced in Chest No. 1. The eggs were examined on May 17, those deposited on May 7-9 and 9-10 were still hatching, while those deposited between May 11 and 14 were unhatched. Examination made on May 19 determined that all eggs had hatched which were deposited between May 7 and 11 and hatching had begun among those deposited May 11-12. No hatching was noted among eggs deposited May 12-14. Examination on May 31 showed that all eggs had hatched. Of 151 eggs deposited May 16-17 and held as checks in the laboratory outside of chests, 13 hatched on May 24 and 138 on May 25.

(9) On May 7, 1921, 36, 38, and 39 eggs deposited, respectively, on May 4-5, 5-6, and 6-7, were introduced into Chest No. 4. Examination on May 12 determined that eggs deposited on May 4-5 had already hatched, but the larvæ had not yet fed; eggs deposited on

May 5-7 were still unhatched. Examination May 21 determined that all eggs had hatched. Of 739 eggs deposited May 6-7 and held as checks in the laboratory outside of chests, 465 were hatched May 14 and 274 on May 15.

(10) On May 7, 1921, 46, 13, and 107 eggs deposited, respectively, May 4-5, 5-6, and 6-7, were introduced in Chest No. 2. Examination on May 11 determined that 1 egg only of those deposited May 4-5 had hatched. Examination on May 21 showed that all eggs had hatched. Of 267 eggs deposited May 4-5 and held as checks in the laboratory outside of chests, 89 were hatched May 12 and 178 on May 13. Of 336 deposited May 5-6 and held as checks in the laboratory outside of chests, 111 were hatched on July 13, 146 on May 14, and 79 on May 18.

EFFECT UPON LARVÆ.

The effect of cedar chests upon larvæ of clothes moths varies with the age and growth attained by the larvæ when they are subjected to the action of the chests. It has been taken for granted in popular entomological literature that larvæ become fully grown during warm weather in from 4 to 10 weeks, but there are no authentic cases recorded of clothes moths actually reared from egg to adult at any season of the year in less than four months.

Observations made in the laboratory at Washington, D. C., during 1920 and 1921 indicate that no definite statement can be made concerning the time it will take clothes-moth larvæ to become fully grown, since their growth varies tremendously when they are fed upon the same material or upon different materials.

These statements seem necessary to indicate to the reader why one can not judge the age of a clothes-moth larva by its size. Clothes-moth larvæ do not mature as fast as has been thought. It is well to understand that larvæ that have become one-half to full grown, regardless of the time required to attain this growth, have been able to cause so much damage and to leave behind them in their feeding so much webbing (Pl. II, B) and sandlike frass that their presence can be detected by a casual examination of the affected garments. Exception is made of certain fur garments where the feeding larvæ lie buried beneath the fur close to the skin; but even in this case the falling of the severed fur will readily reveal damage.

Garments should not be placed in chests without first having been beaten, brushed, and sunned to remove the larvæ. This treatment, advised as a preliminary for all materials intended for storage in cedar chests, if painstakingly done should remove even younger and smaller larvæ. Any larvæ remaining, however, and entering the chests with the clothing are apt to be very young or very small. This is a most important fact, as cedar chests kill only very young or small larvæ.

Since cedar chests can not be depended upon to kill half to full grown larvæ, such articles as balls of yarn, floor skins backed with woolen cloth, infested pillows stuffed with hair or feathers, and similar articles, all portions of which can not be brushed on all sides, might better be treated by fumigation or other methods to kill older larvæ before being placed in cedar chests. Otherwise these articles may be fed upon somewhat in cedar chests by the older larvæ, until they have transformed into moths, but will be protected thereafter.

CEDAR CHESTS DO NOT KILL ONE-HALF TO FULL GROWN LARVÆ.

Cedar chests can not be depended upon to kill larvæ after they are half to full grown, or after they are about three or four months old. To be sure, many of these older larvæ die in the chests, but it is not possible to tell whether their death is caused by the chests or is the result of the high mortality obtaining among any lot of clothes-moth larvæ used in experimental work. The only work done indicating the effect of cedar chests upon the older larvæ is that of Scott, Abbott, and Dudley (17). They say:

In 1915 flannel was placed in this chest, and 10 one-half to three-fourths grown larvæ were added every two weeks until a total of 60 was reached. Examination made two months after the last addition of larvæ showed 7 live larvæ; 36 larvæ had died and 17 had pupated. Of the 17 pupæ 2 died in the pupa stage and 15 emerged as moths, but died before any eggs were laid. The flannel had been fed upon considerably, but was not badly eaten.

Two years later (1917) this experiment was duplicated by adding 25 one-half to three-fourths grown larvæ at one time and allowing the experiment to run 33 days. The results were almost identical with those of the first experiment.

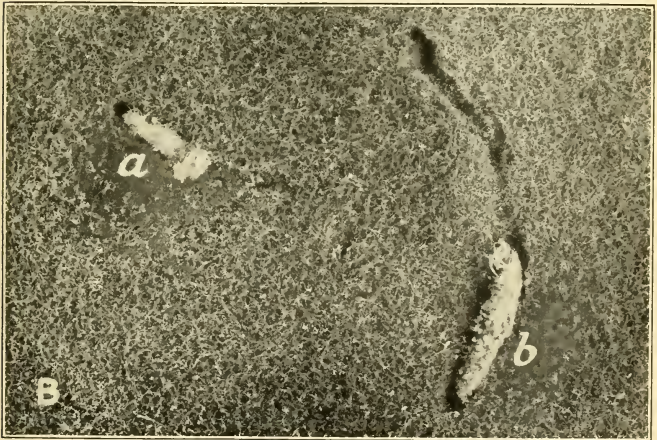
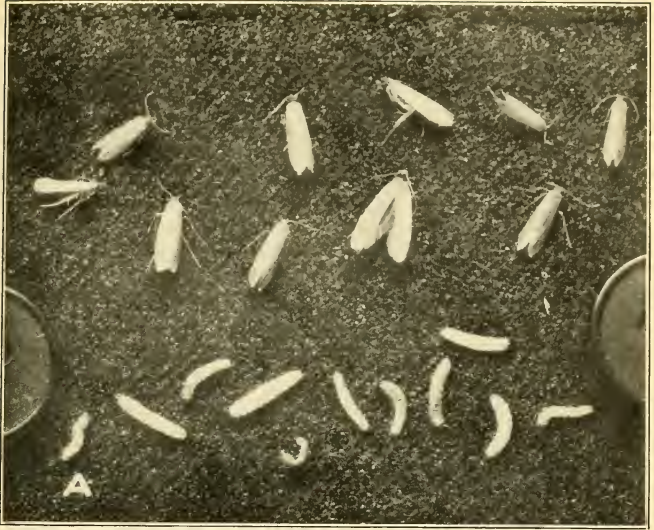
On January 31, 1921, 24 well-grown larvæ were placed in a chest upon a high-grade blue-serge cloth, and 35 others upon a felt pillow top. Both lots of larvæ caused serious damage to the goods by March 2 (Pl. II, fig. 2). During an examination made on that date it was found that of the 50 larvæ 18 were still in the larva stage and alive, 6 had died, 9 had transformed to the pupa stage, and 13 had emerged as adults; the remaining larvæ had eaten through the cloth and escaped into the clothing filling the chest.

Of 100 larvæ (40 well grown, 40 half grown, and 20 very small, but fully four months old) placed on January 31, 1921, in Chest 2 in pill boxes, 13 had emerged as moths by March 2, 16 emerged between March 2 and 17, 19 between March 17 and April 30, and 12 between April 30 and May 11; the remaining 40 died as larvæ or pupæ.

Of 60 well-grown larvæ placed in Chest 1 on January 31, 1921, 2 had transformed to the adult stage by March 2, 9 became adults between March 2 and 17, and 14 between March 17 and May 11; the remaining 35 died either as larvæ or pupæ. Of 50 half to full-grown larvæ placed in Chest 3 on January 31, 13 emerged as adults by March 2. Of the 2, 13, and 13 adults found emerged in Chests 1, 2, and 3 on March 2, developing from larvæ placed in chests on January 31, 1921, 2, 10, and 5, respectively, were alive, while 0, 3, and 8, respectively, were dead.

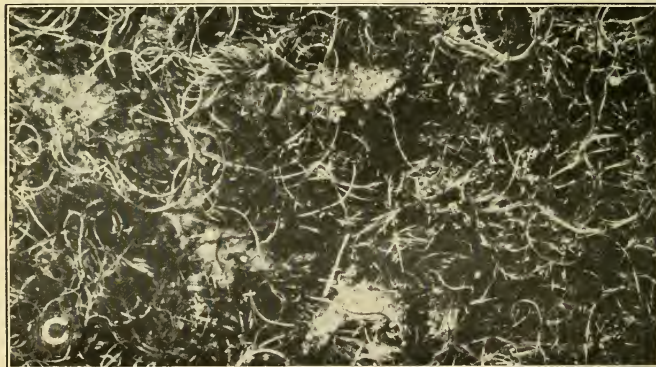
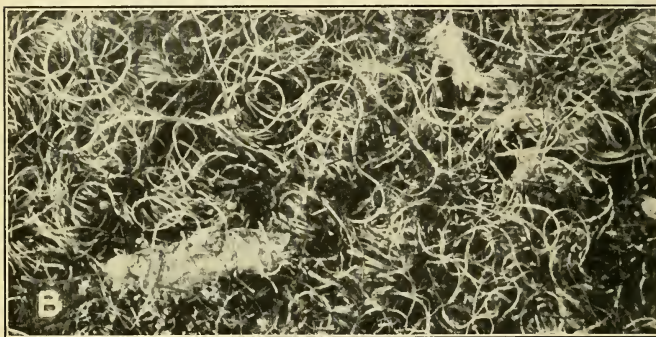
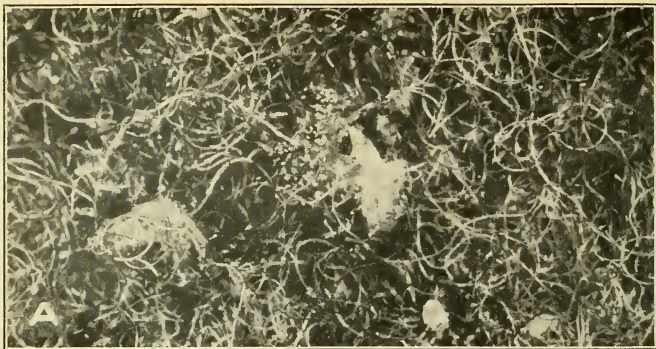
Half to full-grown larvæ placed in Chest 2 on February 11, 1921, developed into adults during the period March 17 to July 27; 1, 1, 8, 6, 4, 3, 7, and 1 being found during examinations made on March 17, 30, April 30, May 11, June 6, July 7, 15, and 27, respectively. The adult found emerged during the July 27 examination, approximately 5½ months after the larvæ were placed in the chest, was alive, very active, and appeared no different in general vitality from others emerging under normal laboratory conditions. One larva of this lot was found alive, normal to all appearances, and very well grown, on July 27, but had died by August 3.

Half to full-grown larvæ placed in Chest 1 on February 11, 1921, developed into adults during the period March 17 to July 23; 1, 8, 3,



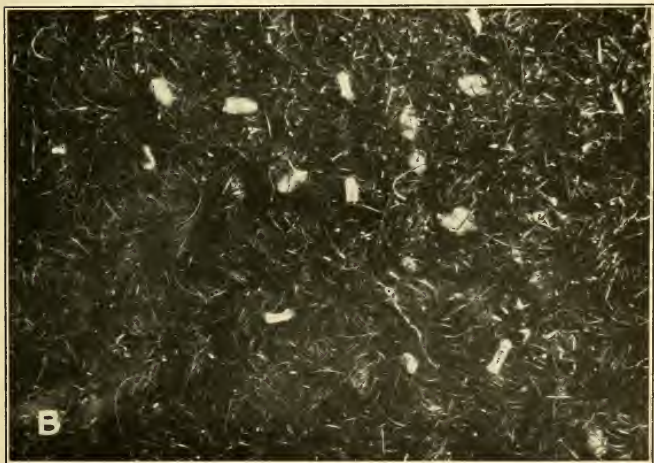
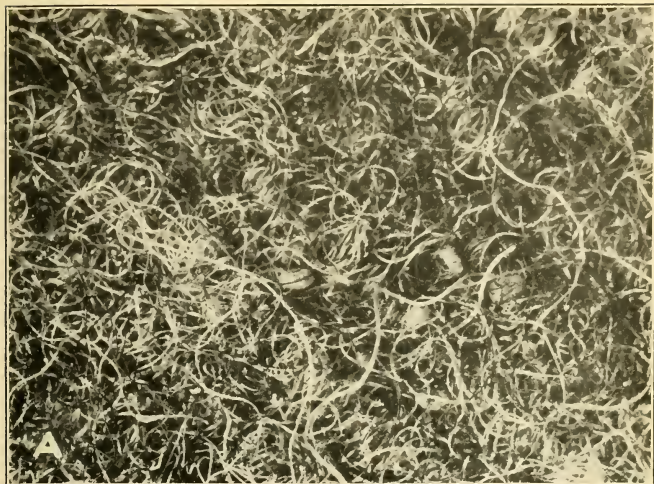
RED CEDAR CHESTS AS PROTECTORS AGAINST MOTH DAMAGE.

A, Adults and well-grown larvæ of *Tineola biselliella*. It is only the larva or worm that damages fabrics. Magnified about 2 diameters. B, Felt pillow top damaged in cedar chest by half to fully grown larvæ of the clothes moth. Beside the damaged portions of goods, note, at *a* and *b*, the whitish tubes of silken threads in which the larvæ secrete themselves while resting. Magnified 2 diameters.



CHEAP GRADE OF ARMY CLOTH SHOWING VARIOUS DEGREES OF WEBBING AND SLIGHT FEEDING BY YOUNG LARVAE OF CLOTHES MOTHS HATCHING INSIDE CHESTS.

The white areas are silken tubes spun by the newly hatched larvæ in which they rest and from the ends of which they feed upon the cloth. A, B, and C represent the maximum amount of webbing ever noted by the authors in any chest. Magnified 12 diameters.



RED CEDAR CHESTS AS PROTECTORS AGAINST MOTH DAMAGE.

A, Eggshells of the clothes moth partially hidden in loosely woven army cloth. Although these eggs have hatched the young larvæ were killed in the chest before they could spin webs or feed upon the fabric. Magnified 12 diameters. B, High grade woolen cloth of moderately close weave. Note eggshells and dead newly hatched larvæ of clothes moths. Larvæ were killed in the chest before they spun webs or fed upon fabric. Magnified about 12 diameters.



WOOLEN CLOTH TAKEN FROM CEDAR CHEST, SHOWING HATCHED EGGS, DEAD YOUNG LARVAE, AND A VERY SLIGHT WEBBING MADE BY THE LARVAE BEFORE DEATH.

This sample of cloth, like those of Plate IV, is not injured by the larvæ of the clothes moth.
The circle indicates a dead larva; the arrow, an eggshell.

5, and 2 being found during examinations made March 17, May 11, June 6, July 7, and July 23, respectively.

Half to full-grown larvæ placed in Chest 3 on February 11, 1921, developed as adults during the period March 17 to June 6; 1, 2, 3, 2, and 1 moths being found during the examinations made on March 17, May 12, May 31, June 6, and July 7.

A miscellaneous lot of 100 larvæ, apparently half to full grown, were placed in Chest 1 on April 9, 1921. Examinations made on May 11, May 31, July 7, July 23, and August 3 showed that there had emerged 53, 2, 7, 0, and 0 adults, respectively. Of 100 larvæ of like age placed on April 9, 1921, in Chest 2, 42, 4, 2, 0, 0, and 0 adults were found emerged on April 30, May 11, June 6, July 7, July 23, and August 3, respectively.

CEDAR CHESTS KILL YOUNG LARVÆ.

Cedar chests have a pronounced killing effect upon young clothes-moth larvæ. Of the larvæ hatching within cedar chests from the 2,074 eggs recorded under the discussion of the effect of chests upon the vitality of the eggs, none were found alive during examinations made one month from the date the eggs were placed in the chests. Exception must be made for one larva hatching from eggs laid April 26-27, which were placed in Chest 3 on April 27, 1921, that was found alive during examinations made on May 12, 21, and 31, but which was dead by June 2.

Practically all larvæ hatching within the chests died within two weeks after hatching and a surprisingly large number died within two or three days of hatching. Exact data on this point are lacking because to obtain them would require the chests to be opened so frequently that their killing power would be weakened. Thus Chest 2 had been opened more often than Chests 1, 3, and 4 just previous to May 21 examination recorded in Table I, with the evident result that its effect upon even very young larvæ was quite seriously affected. Scott, Abbott, and Dudley say (17) that larvæ hatching in chests "died almost immediately." As their examination was made 23 days after the eggs were placed in the chest and as their work was done during warm weather, when the egg stage ranges from 4 to 8 days, their statement should be interpreted to mean that the larvæ died without spinning webs or leaving signs of feeding. The practical point to keep in mind is that larvæ hatching within chests did not as a rule feed (Pl. IV and V) upon the cloth, and when they did, the damage done (Pl. III) would not be observed by the average person.

While the statements made concerning larvæ hatching within the chests from eggs placed there can not be as exact as could be wished because of variations in the length of the egg stage, the age of larvæ recorded in Tables I and II is definitely known and can be compared with larvæ accidentally introduced in clothing into chests. These larvæ hatched in the laboratory and were placed in chests at the ages indicated. In these tables are recorded data secured from each of four chests grouped according to the age of the larvæ and the date of examination. The numbers of the chests refer to the same chests in both tables. It will be seen that larvæ hatching outside the chests and later introduced into the chests do not die immediately,

but may linger along for a considerable number of days. Two larvæ, which were 2 days old when placed in a chest, were still alive (Table II) after 31 days in the chest, but were found dead when examined 6 days later. The majority of the very young larvæ die by the end of the first or second week, without causing damage. The greater resistance of the older larvæ is clearly demonstrated by the data. One $2\frac{1}{2}$ -month-old larva and one 2-month-old larva survived in the chest for over 2 months. Few people should have occasion to place in chests clothing containing larvæ over 1 month old.

TABLE I.—*Effect of four cedar chests upon 520 larvæ ranging in age from 1 day to 3 months, placed in chests on May 14, 1921.*

Age on entering chest.	Chest No.	Date and result of examinations.											
		May 21.		May 31.		June 6.		July 7.		July 23.		July 27.	
		Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	Alive.	Dead.
3 months.....	1	10	0	6	4	4	6	2	8	0	10	.....	.....
	2	10	0	6	4	3	7	0	10	.....	.....	.....	.....
	3	10	0	6	4	.....	.....	0	10	.....	.....	.....	.....
	4	10	0	5	5	3	7	0	10	.....	.....	.....	.....
$2\frac{1}{2}$ months.....	1	10	0	9	1	8	2	1	9	1	9	0	10
	2	10	0	8	2	7	3	1	9	0	10	.....	.....
	3	10	0	8	2	.....	.....	0	10	.....	.....	.....	.....
	4	10	0	6	4	3	7	0	10	.....	.....	.....	.....
2 months.....	1	10	0	9	1	7	3	0	10	.....	.....	.....	.....
	2	10	0	8	2	7	3	3	7	1	9	0	10
	3	10	0	9	1	8	2	0	10	.....	.....	.....	.....
	4	10	0	10	0	9	1	1	9	0	10	.....	.....
$1\frac{1}{4}$ months.....	1	10	0	9	1	7	3	0	10	.....	.....	.....	.....
	2	10	0	10	0	9	1	4	8	0	10	.....	.....
	3	10	0	10	0	8	2	1	9	0	10	.....	.....
	4	10	0	9	1	8	2	0	10	.....	.....	.....	.....
$1\frac{1}{2}$ months.....	1	10	0	10	0	10	0	1	9	0	10	.....	.....
	2	10	0	8	2	8	2	3	7	0	10	.....	.....
	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1 month.....	1	10	0	3	7	2	8	0	10	.....	.....	.....	.....
	2	10	0	7	3	5	5	0	10	.....	.....	.....	.....
	3	10	0	6	4	2	8	0	10	.....	.....	.....	.....
	4	10	0	5	5	3	7	0	10	.....	.....	.....	.....
3 weeks.....	1	8	2	3	7	2	8	0	10	.....	.....	.....	.....
	2	10	0	4	6	0	10	0	10	.....	.....	.....	.....
	3	9	11	3	17	2	18	0	20	.....	.....	.....	.....
	4	10	0	1	9	0	10	.....	.....	.....	.....	.....	.....
2 weeks.....	1	0	10	0	10	0	10	.....	.....	.....	.....	.....	.....
	2	10	0	2	8	0	10	.....	.....	.....	.....	.....	.....
	3	8	2	6	4	2	8	0	10	.....	.....	.....	.....
	4	0	10	6	4	0	10	.....	.....	.....	.....	.....	.....
11 days.....	1	2	8	2	8	0	10	.....	.....	.....	.....	.....	.....
	2	10	0	4	6	0	10	.....	.....	.....	.....	.....	.....
	3	3	7	1	9	0	10	.....	.....	.....	.....	.....	.....
	4	6	4	3	7	0	10	.....	.....	.....	.....	.....	.....
8 days.....	1	1	9	0	10	.....	.....	.....	.....	.....	.....	.....	.....
	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	8	2	2	8	0	10	.....	.....	.....	.....	.....	.....
	4	7	3	2	8	0	10	.....	.....	.....	.....	.....	.....
3 days.....	1	0	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	20	0	2	18	0	20	.....	.....	.....	.....	.....	.....
	3	3	7	0	10	.....	.....	.....	.....	.....	.....	.....	.....
	4	4	6	0	10	.....	.....	.....	.....	.....	.....	.....	.....
2 days.....	1	0	10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	20	0	1	19	0	20	.....	.....	.....	.....	.....	.....
	3	5	5	0	10	.....	.....	.....	.....	.....	.....	.....	.....
	4	4	6	1	9	0	10	.....	.....	.....	.....	.....	.....
1 day.....	1	0	8	0	10	.....	.....	.....	.....	.....	.....	.....	.....
	2	10	0	0	10	.....	.....	.....	.....	.....	.....	.....	.....
	3	.....	.....	0	10	.....	.....	.....	.....	.....	.....	.....	.....
	4	.....	.....	2	8	0	10	.....	.....	.....	.....	.....	.....

¹ Examination made May 7, 1921, showed no mortality among larvæ placed in chests Apr. 30.

² Thoroughly active and normal.

³ Alive but on point of death.

⁴ Larvæ doubtfully dead.

TABLE II.—Effect of four cedar chests upon 520 larvæ ranging in age from 1 to 28 days, placed in chests Apr. 30, 1921.

Age on entering chest.	Chest No.	Date and result of examinations.									
		May 11.		May 21.		May 31.		June 6.		July 7.	
		Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	Alive.	Dead.	Alive.	Dead.
<i>Days.</i>											
28.....	1	5	5	2	8	1	9	1	9	0	10
	2	3	7	1	9	0	10				
	3	3	7	2	8	0	10				
	4	6	4	6	4	3	7	3	7	0	10
21.....	1	6	4	5	5	1	9	0	10		
	2	8	2			0	10				
	3	8	2	3	7	1	9	0	10		
	4	8	2	8	2	3	7	3	7	0	10
14.....	1	6	4	2	8	2	8	1	9	0	10
	2	6	4	1	9	0	10				
	3	3	7	1	9	0	10				
	4	5	5	1	9	0	10				
11.....	1	7	3	2	8	0	10				
	2	5	5	1	9	0	10				
	3	9	1	1	9	1	9	0	10		
	4	6	4	2	8	0	10				
10.....	1	8	2	2	8	0	10				
	2	4	6	0	10						
	3	6	4	3	7	0	10				
	4	6	4	2	8	0	10				
9.....	1	3	7	1	9	1	9	0	10		
	2	8	2	3	7	1	9	0	10		
	3	5	5	1	9	0	10				
	4	8	2	5	5	0	10				
8.....	1	2	8	0	10						
	2	4	6	1	9	0	10				
	3	4	6	2	8	0	10				
	4	5	5	5	5	0	10				
7.....	1	5	5	1	9	0	10				
	2	6	4	1	9	1	9	1	9	0	10
	3	6	4	2	8	0	10				
	4	3	7	0	10						
5.....	1	1	9	1	9	1	9	1	9	0	10
	2	6	4	2	8	0	10				
	3	6	4	4	6	0	10				
	4	6	4	3	7	0	10				
4.....	1	3	7	1	9	0	10				
	2	6	4	4	6	0	10				
	3	2	8	0	10						
	4	4	6	0	10						
3.....	1	3	7	0	10						
	2	6	4	2	8	0	10				
	3	5	5	² 3	7	0	10				
	4	3	7	0	10						
2.....	1	3	7	1	9	0	10				
	2	6	4	¹ 1	9	0	10				
	3	7	3	² 3	7	1	9	0	10		
	4	4	6	1	9	1	9	0	10		
1.....	1	4	6	0	10	0	10				
	2	6	4	1	9	0	10				
	3	4	6	² 1	9	0	10				
	4	7	3	0	10						

¹ Very active and normal in appearance.² Larvæ inactive and doubtfully alive.

CONCLUSIONS.

Chests made of heartwood of red cedar (*Juniperus virginiana*), such as are found on the market, if in good condition as regards tightness, are effective in protecting fabrics from clothes-moth attack if certain precautions are taken to beat, brush, and, when possible, sun articles before placing them in the chest. The writers experimented with chests from the time of manufacture until they were 1 year old, and believe that chests will retain indefinitely their value as protectors against moth ravages provided they are cared for

properly. Since it is the odor of red cedar which is effective against moths it is recommended that in using cedar chests for the protection of clothing, fabrics, and furs, special care should be taken to prevent undue escape of the aroma from the chests. *The chests should remain tightly closed except when clothing is being removed or placed in them, and this procedure should be accomplished as rapidly as possible.* Aside from their value in killing moths, cedar chests are so tightly constructed that adult moths can not gain access to them except when they are open. This is not true of the average trunk or other receptacle in which clothing is stored.

Cedar chests exert no noticeable effect upon the adult moth or miller, the parent insect, which does no damage to clothing but which may lay eggs from which hatch the destructive larvæ, or worms. Moths that run or fly into chests, when open, may live as long as two weeks or even a month, and lay many fertile eggs.

Further, cedar chests are not effective against eggs, no matter whether the eggs are laid outside of the chest and accidentally introduced with the clothing, or whether they are laid in the chest itself. This is true regardless of the age of the eggs when they are subjected to the action of the chest. Imprisonment of adult moths and eggs in a cedar chest, however, is not an important consideration since the young larvæ promptly succumb to the effect of the chest and neither the moth nor the egg eats. However, cedar chests can not be depended upon to kill larvæ after they are 3 or 4 months old, or are from one-half to full grown. Some of the half to full-grown larvæ placed in chests have died, but their death may have been due to a normal mortality. The practical consideration is that many of them were not killed, but continued their development and matured as adults. These larger larvæ are capable of doing considerable damage within the chests though it is believed that their activities are somewhat retarded by the effect of the chests. The older the larvæ when they enter the chest the more resistant they are to this, until finally an age or size, not easily defined, is attained when larvæ are capable of withstanding chests and continue their feeding and development.

Cedar chests do kill young larvæ.—Larvæ hatching from eggs within the chests die in most instances within two or three days, and practically all die within two weeks. Larvæ hatching from eggs outside the chests and introduced into them in clothing do not die so quickly as larvæ hatching inside the chests because they are older, but the majority of such larvæ, which soon show a tendency not to feed, die during the first and second weeks, although some may live longer. Two larvæ, 2 days old when placed in a chest, lived for about 35 days; such resistance, however, is the exception rather than the rule.

It is important that articles intended for storage in cedar chests should be most painstakingly cleaned, beaten, brushed, and sunned whenever practicable to remove or kill as many of the moth eggs and larvæ as possible. Special attention should be given to brushing all seams, creases, and pockets. Clothing thoroughly brushed and sunned should harbor none of the larger or older moth larvæ and very few, if any, eggs and young larvæ. Such clothing if stored at once in good cedar chests should be protected from moth ravages,

for the young larvæ that might be present, or those that might hatch from eggs present in the clothing, would be killed before they could cause serious damage.

Although cedar chests may be regarded as protectors against clothes moths, attention is called to the fact that a chest of ordinary wood, if as tightly constructed, would be just as effective, provided the clothing were as thoroughly cleaned, brushed, and sunned, and from 1 to 2 pounds of good grade naphthalene were packed within.

Woolen garments freshly cleaned and thoroughly brushed will be well protected if tightly wrapped with naphthalene in several thicknesses of ordinary paper. Many persons protect their clothing by carefully cleaning and brushing just before wrapping in paper. In wrapping with paper special attention should be given to turning back the paper at the ends of the bundle that no opportunity to gain access be left for the moths.

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BULLETIN No. 1060

Contribution from the Forest Service
WILLIAM B. GREELEY, Forester

Washington, D. C.



May, 1922

SITKA SPRUCE
ITS USES, GROWTH, AND MANAGEMENT

By

N. LEROY CARY, Forest Examiner

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F-70500

TWO MAGNIFICENT SPECIMENS OF SPRUCE IN ALASKA.



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INTRODUCTION.

Sitka spruce (*Picea sitchensis* (Bong.) Trautv. and Mayer), also called tideland spruce, is an important timber tree of the Pacific coast region, growing naturally from Alaska to northern California. It is found largely at low altitudes and never very far from the ocean. In Alaska it is the principal tree of commerce; in Oregon and Washington it is one of the components of the dense and luxuriant coniferous forest that blankets the humid strip of country on the west side of the coastal ranges. Here several of its associate trees are more abundant than Sitka spruce; but in the superior qualities of its wood, in its magnificent form, and in its immense size it has no superior except the redwood with which it mixes at the south end of its range.

Because Sitka spruce does not ordinarily occur in pure stands, it must be logged in conjunction with other timber species—with Douglas fir, western hemlock, and western red cedar in Washington and Oregon, and with the western hemlock in Alaska. The greater part of the virgin forests in which Sitka spruce occurs has not been

NOTE.—The writer wishes to acknowledge the valuable assistance given him by Messrs. H. T. Gisborne, R. H. Weidman, and others in the preparation of this manuscript.

reached by lumbering operations; hence until recently the cut of this timber had been relatively small. It was not well known in the world or national markets until an extraordinary demand for it arose during the war because its wood was found to be superior for airplane construction. Within the space of a few months in 1917 this species, which had been of decidedly secondary importance in the lumber industry, became one of the woods most eagerly sought. To effect an enormous increase in the production of Sitka spruce and to obtain lumber of the quality needed for airplane wing beams, a special organization of the War Department—the Spruce Production Division—was created. The great activity of this organization in promoting the lumbering of this needed Sitka spruce airplane stock in conjunction with the local lumber industry is one of the interesting chapters in the history of the war industries.¹

Although Sitka spruce may never again be so eagerly sought and so extensively cut as during the war, it has so many superior qualities in the estimation of foresters and lumbermen that it will always play an important rôle in the forest management of the Pacific coast region. It has a habit of rapid growth, makes a large yield per acre, lends itself fairly well to forest management, and produces a wood which has large value for many special purposes, prominent among which is the manufacture of paper.

GEOGRAPHIC DISTRIBUTION AND ALTITUDINAL RANGE.

The botanical range of Sitka spruce, as shown in figure 1, lies along the north Pacific coast, roughly between 40° and 60° of latitude, and in that narrow strip of shore line often described as the fog belt. Its width is nowhere more than 200 miles from the coast line eastward, and usually much less.

In Alaska this species occurs as far north as the west shore of Cook Inlet, the north end of Kodiak Island, and along the Lynn Canal, and is generally abundant southward, on the islands and mainland near the coast of southeastern Alaska. In British Columbia it is found chiefly along the shore line and on the lowlands of the large rivers like the Fraser.

In the United States it is found in the western part of the State of Washington on the lower benches and bottomlands of the rivers along the Pacific coast, and less commonly about Puget Sound, occurring sporadically in the foothills of the Cascade Range. In Oregon it is found under similar conditions but almost exclusively west of the crest of the Coast Range; it extends up the Columbia River only 50 miles from its mouth, and farther south not more than

¹ "History of Spruce Production Division, United States Army," issued by the United States Spruce Production Corporation.

20 miles inland. In California it grows close to the shore line and along the Smith and Klamath Rivers; the southern limit of its range is near Casper, in Mendocino County.

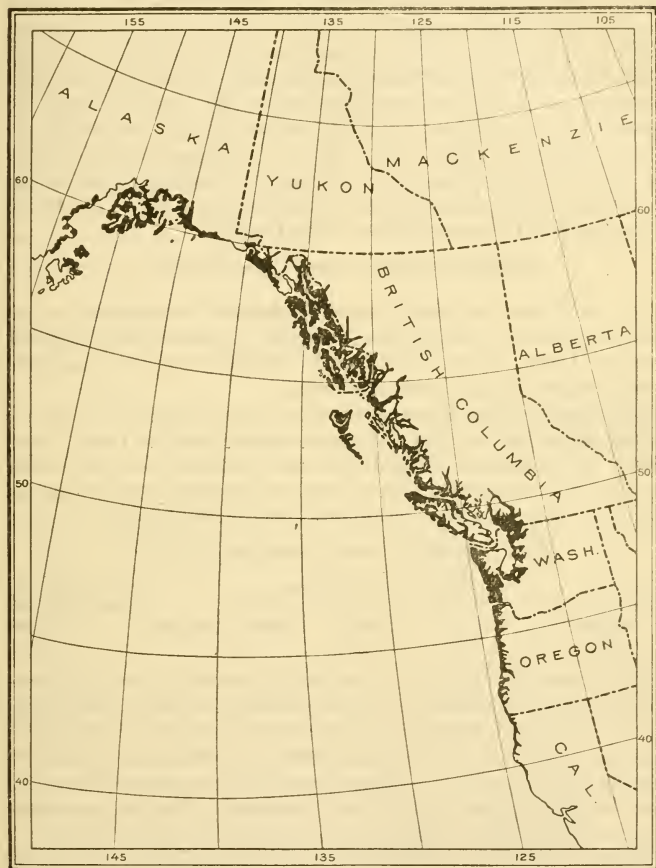


FIG. 1.—Botanical distribution of Sitka spruce, shown by shaded areas.

Heavy commercial stands of this species are found all the way from southeastern Alaska to Coos Bay, Oreg., though by no means does this tree preponderate in the forest growth throughout this strip nor is it even present everywhere. The heaviest stands of Sitka spruce, in its entire range, occur in the northwestern part of the

Olympic Peninsula (Washington) along the Soleduck, Dickey, and Hoko Rivers at elevations between 400 and 600 feet.

The upper altitudinal limit has been noted by many observers as being higher in the northern part of its range than farther south; it is seldom, however, more than 3,000 feet above sea level. In the States it is doubtful whether it grows at that elevation; actually it has been found at 2,500 feet on the west side of the Olympic Mountains, at 2,100 feet near Bandera in the Cascade Range of Washington, and at about 2,100 feet on the slopes of Saddle Mountain in Clatsop County, Oreg. (Pl. I.) Although botanically it does occur at these elevations, an altitude of about 1,200 feet marks the upper limit of its growth in commercial quantities. The lower limit extends to the very surf line of the Pacific.

PRESENT SUPPLY AND ANNUAL CUT.

The total stand of Sitka spruce in America is estimated at 40 to 44 billion feet. As shown in Table 1, more than one-third occurs in Alaska, one-third in British Columbia, and the remainder in Washington, Oregon, and California.

It is estimated that about 1,600 million board feet of the most accessible spruce has been cut since the estimates given in Table 1 were made.² An additional billion board feet is estimated to have blown down by the catastrophic wind storm of January, 1921, which occurred in the heart of the Sitka spruce belt of Washington.

TABLE 1.—*Estimated stand of Sitka spruce in 1918.*³

State:	Million feet b. m.	State:	Million feet b. m.
Washington	6, 575	Alaska	15, 000 to 18, 000
Oregon.....	4, 374	British Columbia	15, 186
California.....	187		

Sitka spruce forms only 1.5 per cent by volume of the total merchantable stand of timber west of the Cascades in Oregon and Washington. In British Columbia it comprises 6.7 per cent of the timber along the coast. Of the coastal forests of southeastern Alaska it forms about 20 per cent. Approximately 50 per cent of the entire stand of Sitka spruce is in private ownership. Detailed estimates of ownership appear in Table 10.

The cut of spruce in Washington and Oregon increased over 50 per cent in the year 1918, and practically all of this increase was made up of Sitka spruce. The cut of spruce in the United States increased very little, and in general is declining. For a number of

² "Supplies and Production of Aircraft Woods," by W. N. Sparhawk, National Advisory Committee for Aeronautics, Fifth Annual Report. Rpt. 67, p. 9, 1919.

³ Figures for all localities except British Columbia compiled by Forest Service from county records and private, State, and Government estimates. British Columbia figures from "Forests of British Columbia," by H. N. Whitford and R. D. Craig, p. 330, 1918.

years Maine had been the leading spruce-producing State, cutting chiefly red spruce; but the pressing need for spruce aircraft lumber for war uses stimulated production in the Pacific Northwest to such an extent that in 1918 Washington took first place in the production of spruce with a cut of over 275,000,000 board feet, Oregon second with a cut of over 215,000,000, while Maine dropped to third place. As is shown in detail in Table 2, the cut of spruce for 1918 comprised 6 and 8 per cent, respectively, of the total lumber production in Washington and Oregon, less than 2 per cent in California, and practically the entire cut in Alaska. No distinction is made between species of spruce, but Sitka spruce probably forms over 95 per cent in these three States. In British Columbia the ratio was about the same as in Washington. The total cut of Sitka spruce in 1918, exclusive of British Columbia, exceeded 536,000,000 board feet.

TABLE 2.—*Total reported cut of spruce lumber, 1915-1918.*

[No distinction is made between species of spruce; Sitka spruce probably forms over 95 per cent in Washington, Oregon, and California.]

Year.	Number of active mills reporting.	Quantity of spruce reported cut.	Per cent of total lumber cut.	Per cent of total spruce cut in United States.	Average value per 1,000 feet f. o. b. mill.
		<i>M feet. b. m.</i>			
Washington:					
1915 ¹	49	196,203	5.3	16.4	\$14.08
1916 ²	65	221,295	5.0	19.6	14.08
1917 ³	66	198,271	4.6	20.3	22.34
1918 ⁴	60	275,826	6.0	28.1	23.91
Oregon:					
1915 ¹	20	65,327	4.3	5.5	13.56
1916 ²	23	96,245	4.3	8.5	11.96
1917 ³	26	120,647	4.9	12.3	28.28
1918 ⁴	35	215,828	8.0	22.0	27.03
California:					
1915 ¹		9,477	0.8		
1916 ²	2	13,871	0.9	1.2	14.44
1917 ³	4	20,659	1.5	2.1	17.50
1918 ⁴	8	16,663	1.3	1.7	20.75
Alaska: 1918 ⁵	18	28,716	98.0		23.00
British Columbia:					
1915 ⁶	49	756,360			13.60
1916 ⁶	48	749,077	5.6		14.66

¹ "Production of Lumber, Lath, and Shingles in 1915 and Lumber in 1914," U. S. Dept. Agr. Bul. 506, p. 20.

² "Production of Lumber, Lath, and Shingles in 1916," U. S. Dept. Agr. Bul. 673, p. 21.

³ "Production of Lumber, Lath, and Shingles in 1917," U. S. Dept. Agr. Bul. 768, p. 21.

⁴ "Production of Lumber, Lath, and Shingles in 1918," U. S. Dept. Agr. Bul. 845, p. 24.

⁵ "Character and Distribution of the 1918 Lumber and Shingle Cut of Washington, Oregon, and Alaska, by Producing and Consuming Regions," by T. J. Starker, West Coast Lumberman, Vol. 36, No. 423, p. 26, 1919.

⁶ "Forests of British Columbia," by H. N. Whitford and R. D. Craig, p. 178, 1918.

⁷ No distinction is made between species of spruce; probably about 80 per cent Sitka spruce.

CHARACTERISTICS OF THE WOOD.

Sitka spruce wood is light, soft, straight-grained, tough, easily worked, and very strong for its weight. It is tasteless and contains very few resin ducts. The color of the heartwood is a pale pinkish brown, which blends imperceptibly into the creamy white of the

sapwood. The longitudinal surface of the wood shows a silky sheen, and the tangential surface, less noticeably, slight indentations or dimples. There is no distinct line of demarkation between the springwood and the summerwood as in Douglas fir.

Compared with other woods of similar weight, Sitka spruce is of greater strength and toughness. Table 17 (Appendix) shows the value of its mechanical properties as measured by laboratory tests. Individual test specimens may show a variation of as much as 16 per cent from the data on bending, compression, shearing, tension, and such properties.

Spiral grain is found in Sitka spruce as in other species, though not to any great extent. During the war specifications for airplane stock required that no spiral-grained wood be accepted which had more than 1 inch departure in 20 inches of length. Tests showed that a greater amount of twist caused a marked reduction in strength for aircraft purposes. Spiral grain in Sitka spruce can generally be detected in the standing tree by a twisting of the fluted portions of the lower trunk.

The calorific power of one cord of air-dried Sitka spruce wood is 52 per cent of that of a short ton of coal, and that of western hemlock and Douglas fir is 58 and 68 per cent, respectively.

USES.

The varied properties of Sitka spruce fit it for a wide variety of uses. It is the premier wood for the manufacture of aircraft. It is unsurpassed for pulp and is especially adapted for musical instruments. It is also a desirable wood for boxes, crates, barrels, veneer, and woodenware.

By far the most extensive use to which the wood is put is the manufacture of lumber. As such, in one form or another, it is used for about the same purposes as the other spruces. About 40 per cent is used for construction and similar purposes without further manufacture. While not suitable for heavy construction, it is well adapted for many building uses in which light weight, ease in working, and ability to take and hold nails and paints are essential. It is especially suitable for large doors, such as are used for garages, freight houses, and similar structures. It is extensively used for beveled siding. As a car stock it is unsurpassed. The bulk of the lumber, however, is remanufactured into a large variety of products.

More than half the lumber cut of this species is consumed by the planing mill, box, and crate industries. It cuts to advantage for doors, window and door frames, and molding. Belonging to the class of tasteless woods, Sitka spruce is extensively used for containers in which articles of food are packed or handled.

Because of its light weight, combined with strength and toughness, Sitka spruce is the most desirable and most generally used wood for such airplane parts as wing beams, struts, longerons, ribs, and plywood parts. Although red, white, and Sitka spruce do not differ greatly in strength properties, the last species, on account of its greater size and consequently its greater proportion of clear lumber, is a more important source of aircraft material than the other two. Because of this and the relatively large supplies of virgin timber still remaining, Sitka spruce will probably for many years be a very important species in the aircraft industry, notwithstanding the fact that the supply is far from the centers of manufacture.

Because of the resonant quality of the wood, its even structure, the absence of vessels, the extremely fine and regularly distributed medullary rays, and the straight and long fibers, spruce generally is considered to be the best wood for piano sounding-boards, as well as for musical instruments generally. Sitka spruce yields a large proportion of clear lumber and wood of selected quality for this purpose, but its rapid growth tends to lessen the resonant quality in comparison with the slower growing eastern species.

The wood is not durable in contact with the soil or when exposed to weather. It is less suitable for piling in salt water than are other species, because of its greater susceptibility to the ravages of the teredo, which may destroy it in one or two years.

For the manufacture of white paper pulp by either the mechanical or the chemical process, spruce is the leading wood used. It is soft, white, and nonresinous, and its fibers are longer, more flexible, and stronger than those of most woods. Containing a maximum percentage of cellulose, it gives a high yield by the chemical process. Although there are several species of spruce, no marked difference is noted in the pulps manufactured from them. A comparison of the character and uses of the pulp made from Sitka spruce with that made from white spruce, a wood that can be considered standard for pulping by the sulphite, sulphate, and mechanical processes, indicates no practical difference.

Because of the long distance to the large paper markets of the East, the utilization of Sitka spruce for paper manufacture is relatively small. Of the domestic spruce consumption in the United States in 1918 for the manufacture of paper, 35,385 cords, or 1.6 per cent, was Sitka spruce from the forests of Washington and Oregon. British Columbia utilizes about half as much Sitka spruce for this purpose as do the States of Oregon and Washington. Other species, including western hemlock, white fir, cottonwood, and Douglas fir, are utilized on the Pacific coast in the manufacture of pulp, but Sitka spruce represents about 15 per cent of the total.

The pulp, paper, and board industry of the West, a long-established one, is confined practically to the Pacific coast, with the pulp mills largely confined to the States of Oregon, Washington, and the province of British Columbia. Alaska has one pulp mill, established in 1921. There is every indication that this industry will grow rapidly in the next few years, with an abundant supply of pulp-wood, waterpower, and coal, taken in connection with the fact that the pulp-wood supply in the East is approaching depletion.

LOGGING AND MILLING.

The occurrence of Sitka spruce on the lowlands near tidewater, and along navigable or drivable rivers, on the benches and gently rolling country of the lower foothills makes logging relatively easy, and a mild climate permits year-long operation. As the species occurs largely in association with Douglas fir, hemlock, and cedar, the method of logging is identical with that universally used in the heavy forests of the Pacific coastal region. Here large operations, powerful steam machinery, and heavy capital investments are the distinctive features of logging operations. (Pl. II.) These are required by the large size of the timber, the ground conditions, and the enterprise of the industry.

Trees 6, 8, or 10 feet in diameter, standing on rough steep ground, are felled and converted into logs in such a way that the minimum of waste results; and logs, some of them scaling 10,000 feet and weighing 30 tons, are dragged with great dispatch over the ground or swung down steep slopes and over deep canyons on overhead cables. The greater part of the timber is transported from the woods to the mills or waterside over standard-gauge logging railroads for distances ranging from a few miles to 30 or more. (Pl. III.) To a limited extent motor trucks (Pl. IV) are used in conveying logs, and in some cases in the Grays Harbor and Willapa Harbor regions of Washington logs are transported by driving streams. A large percentage of the cut of Sitka spruce reaches the waterside along the Columbia River and in Puget Sound, Grays Harbor, and Willapa Harbor, where the logs are made into rafts and towed to the mills.

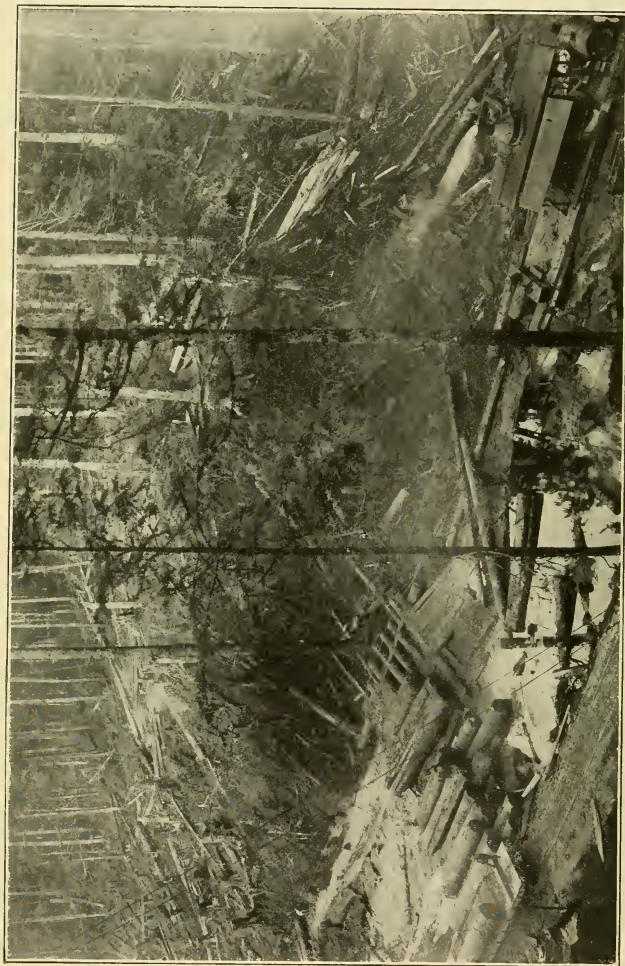
Logging with animals in Oregon and Washington is confined to small operations getting out ties, shingle bolts, piles, and poles. In Alaska, operations are found only along the shore line, and there both hand and machine methods are employed. If the latter method is used the donkey engine is mounted on a float, the hauling line is led inshore a thousand feet or more, and the logs are skidded directly to the water to be towed to the mills.

The sudden and urgent demand in 1917 for high-grade spruce timber for airplane material, which existing logging operations were



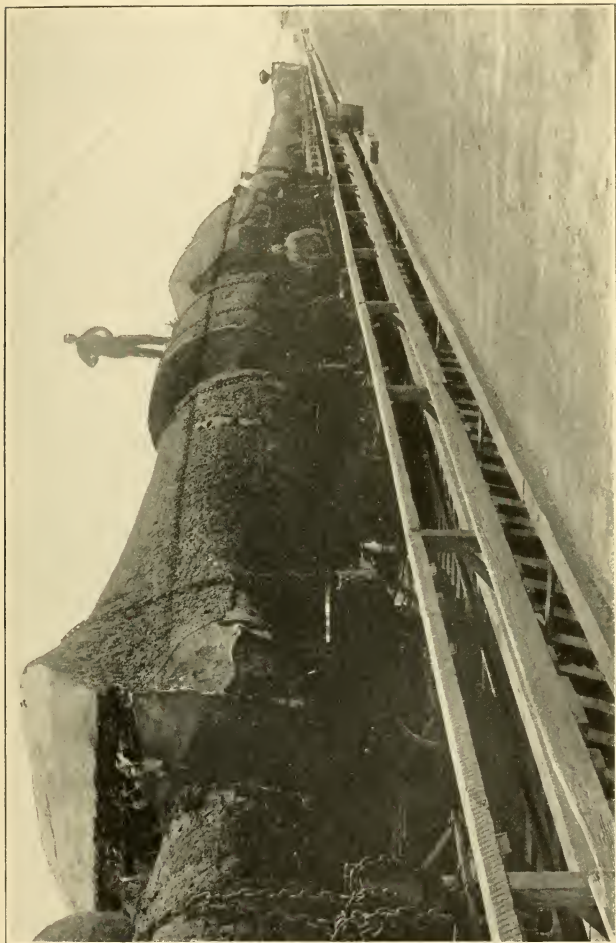
F-NLC-1

GROUP OF SITKA SPRUCES IN CLATSOP COUNTY, OREG.



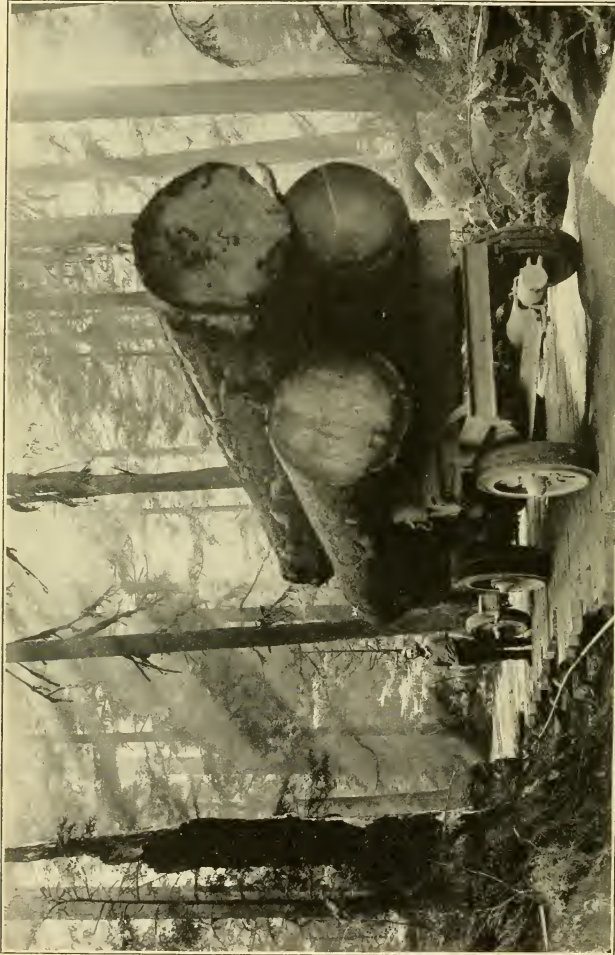
F-NLC-2

STEAM LOGGING IN SITKA SPRUCE, SHOWING DONKEY ENGINE AND LANDING.



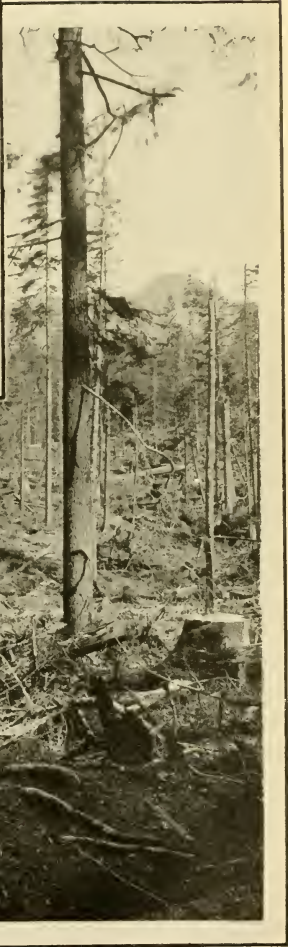
F NLC-3

A TRAINLOAD OF LARGE SITKA SPRUCE LOGS AT BOOMING GROUNDS.



F-NIC-4

TRANSPORTATION OF LOGS BY AUTO TRUCK.

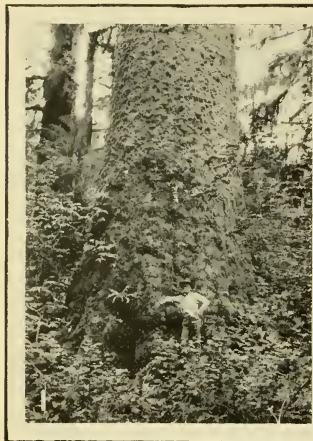


F-NLC-5



F-NLC-6

FIG. 1.—RIVING FOR CLEAR AIRPLANE MATERIAL. FIG. 2.—DÉBRIS AFTER SELECTIVE LOGGING.



F—S50842

FIG. 1.—LARGE SITKA SPRUCE NEAR BEAVER, WASH., MEASURING 16 FEET IN DIAMETER.



F—NLC-7

FIG. 2.—SAME AS FIGURE 1, SHOWING BROKEN TOP.



F—NLC-8

FIG. 3.—TWO BIG STUMPS IN CLATSOP COUNTY, OREG., SHOWING FLARE OF THE ROOTS.



F-70501

TYPICAL FOLIAGE, CONES, AND BARK OF SITKA SPRUCE.



F-70502

BASAL SWELL IN SITKA SPRUCE IN ALASKA.

unable to meet, caused the Spruce Production Division to encourage small isolated operations to rive out by hand cants of clear spruce from selected trees. By means of wedges and jacks huge logs were split to obtain cants of clear, straight-grained wood, which were dragged from the woods, usually by horses, and sent to resaw plants. (Pl. V, fig. 1). That method of logging was discarded later in favor of a plan of logging selected trees on a larger scale, and this method resulted in a more rapid production of high-grade spruce.* In logging selectively an area was combed of all trees which were of airplane quality, and the others were left standing. This method avoided the cutting of low-grade spruce and other timber for which there was no market.

The cost of logging Sitka spruce has varied widely, more particularly during and since the war. Before the war the average cost of logging was about \$5.50 per thousand feet; in 1919 it amounted to approximately \$11 per thousand feet; and in 1920 it was somewhat higher.

Sitka spruce timber is normally cut into logs ranging from 32 to 40 feet in length. As about 40 per cent of all timber cut on the Pacific coastal region is logged by operators engaged solely in logging, who sell their logs in the open market, logs are graded according to size and quality into No. 1, 2, and 3 logs. It is estimated that Sitka spruce timber as logged will grade: Twenty per cent No. 1 logs, 40 per cent No. 2, and 40 per cent No. 3. Prior to the war Sitka spruce logs sold for about \$12, \$9, and \$6 per thousand for No. 1, 2, and 3 logs, respectively. In 1920 they sold for \$30, \$24, and \$18 on this basis. At the height of war-time operations in 1918 a price of \$35 for No. 1 logs was reached.

Most of the Sitka spruce lumber that is manufactured in the United States is cut in the large band sawmills of the Coos Bay district of Oregon and the Grays Harbor and Willapa Bay districts of Washington. The sawmills of Alaska, with a daily capacity of 25,000 to 40,000 board feet of lumber, are smaller comparatively.

The cost of manufacture before the war was a little less than \$5.50 per thousand feet; in 1919 it amounted to about \$12, and in 1920 it was a little higher.

Although exceedingly high prices were paid in 1918 for clear lumber suitable for aircraft construction, the average wholesale value of mill-run Sitka spruce in that year varied from \$20 to \$27 per thousand board feet. (See table 2.) Before the war an average price of about \$14 obtained. Prices on January 1, 1919, are given in table 3.

* "History of Spruce Production Division," 1919.

TABLE 3.—*Range in selling prices of different grades of spruce lumber (f. o. b. mill), January 1, 1919.*

Grade.	Price per 1,000 ft. b. m.
"B" and better, finish, S2S-----	\$35. 00 to \$62. 00
Factory select and better, S2S-----	35. 00 to 62. 00
No. 1 shop, S2S-----	32. 00 to 39. 00
Shop common, S2S-----	30. 00
No. 2 shop, S2S-----	27. 00 to 34. 00
Box, Nos. 1, 2, and 3, S2S-----	26. 00 to 28. 00
Common boards, S2S-----	25. 00
Common dimension, S1S1E-----	17. 50 to 30. 00

Regarding the prices of Sitka spruce stumpage, it may be said that they varied as greatly in the last few years as did logging and milling costs. Ten years ago average stumpage was worth about \$1.50 per thousand feet. Just prior to our entrance into the war it was about \$2.75 per thousand feet, and in 1920 it reached \$3.50. During 1918 stumpage values of selected trees to be cut in riving or logging operations ran as high as \$7.50 per thousand feet. Sitka spruce stumpage, of course, like that of other species, varies in value with topography and accessibility. For this reason values greater than those given here, as well as values considerably less, have obtained.

SIZE, AGE, AND DISTINGUISHING CHARACTERISTICS.

SIZE.

Sitka spruce, which is the largest of the spruces, grows to a size comparable with the maximum for Douglas fir and cedar, and larger than its other associates.

When maximum sizes are considered, individual specimens of Sitka spruce have been found to attain surprisingly large proportions. Total heights of 296, 285, and 282 feet were recorded in the course of the field work for this study for individuals found in the vicinity of Quinault Lake and Beaver, Wash. All these trees were under 300 years of age. Specimens which measured over 9 feet in diameter at a height of 10 feet above ground were found not merely once or twice, but many times, in both Oregon and Washington forests. The largest diameter recorded was of a tree which grew near Beaver, Wash. It measured 16 feet in diameter at breast height, and because of its gradual basal taper was of large volume (Pl. VI, figs. 1 and 2). Necessarily, large diameters and heights mean large volume, and individual trees in Oregon and Washington occasionally have scaled 40,000 board feet in merchantable contents; but the average tree scales about 8,000 board feet. In Alaska single trees have scaled 24,000 board feet of merchantable material.⁵

⁵ "Production of Airplane Lumber in Alaska," by W. G. Weigle, *Alaska Pioneer*, vol. 1, No. 2, p. 4, 1918.

The species attains its maximum development in Washington and Oregon. The average tree found in the virgin forest has a height of about 230 feet and a diameter of 4 feet, measured 15 feet above ground. North of the optimum range in British Columbia it grows to maximum diameters of 8 to 12 feet and heights of 160 to 180 feet; but ordinarily it is only 3 to 6 feet in diameter.⁶ In Alaska, too, its average diameter is 3 feet and its height about 150 feet, but single trees frequently exceed this. In California it is smaller than farther north and becomes only a medium-sized tree. This subject is discussed more fully under the heading "Growth."

LONGEVITY.

Sitka spruce is a long-lived tree. Sudworth reports a maximum age of 750 years.⁷ During the recent study, however, the oldest tree that could be found was 586 years of age. It is doubtful whether many individuals ever reach an age of over 600 years, and the mean mature age is not more than 450 years.

DISTINGUISHING CHARACTERISTICS.

An outstanding characteristic of the appearance in the forest of Sitka spruce is its bark (Pl. VII). The thin, stiff, cupped, and elliptical dark purple-gray scales 1 or 2 inches in diameter make this species easily distinguishable from its associates in the stand. Little protection is afforded to the living tissues, however, by the bark, which is only one-half to 1 inch thick.

The needles are also of distinctive appearance. In spring the yellowish green color of new needles in sprays that bend downward limply at the ends of the branches stands out in contrast with the dark bluish green of the older needles; and although the young leaves are soft and velvety to the touch, during the remainder of their 5 to 6 year existence they are stiff and stand out straight in all directions around the twig, each needle tip being keenly pointed and quite bristly to the touch. The leaves are somewhat flattened, only indistinctly four-angled, and about 1 inch long.

The cones, too, exhibit peculiarities by which this species may be identified. They have an average length of 3 inches, are light brown in color, elliptical in shape, and hang down conspicuously from the upper branches. The cone scales are thin and papery, with irregular margins but slightly pointed in general outline, and are firmly attached to the central stalk of the cone. Maturity is reached at the end of one year's development; soon thereafter the scales open and release the small dark brown seeds with their large thin wings adhering to them. Most of the cones drop from the

⁶ "Forests of British Columbia," by H. N. Whitford and R. D. Craig, p. 199, 1918.

⁷ "Forest Trees of the Pacific Slope," G. B. Sudworth, p. 83, 1908.

tree soon after the seeds have been scattered by the wind, but some cones may remain on the branches for a number of years.

The root system is characteristically shallow. This is especially true of trees on swampy soils where the roots spread out very close to the surface; but on deep, porous soils they penetrate 4 to 5 feet into the ground and occasionally as far as 12 feet.

Characteristics of form are unimportant, with one exception, for the recognition of this species. In general, the forest-grown trees are tall, with open, conical crowns and long, cylindrical boles. Their bases are very commonly heavily buttressed. Plates VI (fig. 3), VIII, and IX show the importance of this fact when form is considered. Plate IX, figure 2, gives one clue to its cause; the stumps illustrated in this plate were those of only two out of seven fully grown trees that developed on this one windfall. Basal or butt swell is common in this species and especially so in trees which occur on the lowlands. Incidentally, it should be mentioned that this condition in the tree very materially affects any diameter measurements, for the standard practice in all species is to measure diameters at a uniform height of $4\frac{1}{2}$ feet above the ground, and this practice would give very inconsistent results with large Sitka spruces. Further discussion of this point appears under "Diameter growth." The overmature trees present another characteristic, that of stag-headedness. (Pl. VI, fig. 2.) Such broken-topped trees are apt to develop ascending side branches, and these may grow to 14 inches and more in diameter and 50 feet in height. Trees in this condition, as shown by the cedar snags in Plate XIV, may be called bayonet-topped.

OCCURRENCE.

Sitka spruce stands are found on a variety of sites but may be grouped broadly into two classes—the bottomland or lowland, and the slope or highland. The development of the tree, which to a great extent is influenced by the amount of soil moisture, is the chief difference between the two types, and the altitudinal situation is of only minor consideration. The forest may be of pure spruce or of spruce in mixture with other species. These types occur throughout the range of the species, and a third or "upper slope" type might be added for Alaska to include the bodies of scrubby spruce near the upper altitudinal limit of tree growth.

BOTTOMLAND TYPE.

This type is found in the moist situations of river bottoms and benches above the river beds where there is a deep, rich alluvial soil, and where in places the heavy precipitation of the winter and spring months has so saturated the ground that standing water is not un-

common. Here the trees, though large and tall, are characterized by large buttressed bases, limbiness, and comparatively short clear length. On these moist sites the trees make a noticeably rapid and well-sustained diameter growth, especially from 100 to 200 years of age. In this type Sitka spruce occurs also on tidelands and in swamps where there is considerable inundation; but, although it can stand these conditions, it prefers an excess of soil moisture only with good drainage and in general avoids stagnant sites and acid soils. In contrast with the stands on the bottoms and benches, those in swamps are quite frequently pure, but the trees here are shorter and much more limby. Trees which occur on exposed situations along the coast are small and scrubby and unfit for commercial uses.

SLOPE TYPE.

Spruce stands of the slope type are found on the moist but well-drained hills which border the lowlands and which afford all advantages for excellent growth in their rounded ridges and gentle slopes of deep, rich soil. It is not only in the upland country that this type occurs; similar conditions exist on the rolling, sandy land along the coast. The trees on such sites are fine specimens, large and tall, with long, clear length; and, in contrast with those of the bottomland type they seldom develop buttressed bases. (Pl. XI.) The wood is characteristically fine-grained, and this fact is frequently mentioned by lumbermen as a means of distinguishing between trees of the two types. Spruce in these stands is more often pure than in mixture, and this is especially true on the sandy lands which border the ocean. (Pl. XII.)

COMPOSITION AND VOLUME OF STAND.

Pure stands of Sitka spruce are usually not extensive but are apt to be limited to patches of a few acres in contrast with Douglas fir, which occurs pure over great areas. Larger pure forests of spruce are found occasionally, however, 40 or more acres in size in Oregon, Washington, and British Columbia, and even 100 acres in Alaska; but this is the exception rather than the rule.

When Sitka spruce grows in mixture with other species, the most common associate is western hemlock, and large areas of these two species are found in Alaska and in the States as well. Sitka spruce is also associated with Douglas fir, western red cedar, lowland white fir, silver fir, and Pacific yew throughout the range, with Port Orford cedar and redwood only in southern Oregon and California, and with Alaska cedar and mountain hemlock on the upper slopes in British Columbia and Alaska. In the valley bottoms it occurs with such hardwoods as broadleaf maple, black cottonwood, and red alder. (Pl. X.)

The composition of a typical piece of what is distinguished as the "western hemlock-Sitka spruce type" in British Columbia is as follows:⁸

	Per cent.
Western hemlock	38
Sitka spruce	27
Western red cedar	15
Balsam (silver) fir	15
Others (Alaska cedar and cottonwood)	5
	100

A summary of cruises made in 1918 in spruce stands on the west side of the Olympic National Forest in Washington shows the following average composition of the forest:⁹

	Per cent.
Western hemlock	37
Douglas fir	26
Sitka spruce	21
Silver fir	7
Western red cedar	6
Others	3
	100

The mixed forest is usually of even age; infrequently it is of two age classes, and then the hemlock trees are the smaller and younger ones of the stand. An all-aged forest occurs but rarely, and then as an open stand on swampy soils.

An idea of the composition of the stand and the representation of small-sized trees of other species (in the older stands) may be gained from Table 4. This table shows the results of measurements on 12 sample plots in typical stands in Oregon and Washington in which Sitka spruce comprised from 50 to 100 per cent of the volume of the stand.

TABLE 4.—*Number of trees of Sitka spruce and other species per acre for typical stands of various ages.*

Plots.			Living trees per acre.				
Designation and locality.	Area.	Age.	Sitka spruce.		Other species.		Total.
			Under 12 inches.	Over 12 inches.	Under 12 inches.	Over 12 inches.	
	<i>Acres.</i>	<i>Years.</i>					
Newport III.....	0.4	27	448.0	122.0	30.0	0.0	600.0
Blodgett I.....	.2	60	104.0	112.0	24.0	32.0	272.0
Raymond I.....	4.0	70	1.5	27.7	25.2	98.0	152.4
Newport I.....	2.0	130	2.5	61.0	3.0	8.0	74.5
Tsiltcoos II.....	2.0	175	1.5	49.5	10.0	13.5	74.5
Raymond II.....	4.0	175	3.5	13.2	13.8	41.2	71.7
Hoquiam I.....	4.0	240	.0	18.0	28.2	18.8	65.0
Beaver I.....	4.0	260	.2	18.2	5.3	9.6	33.3
Tsiltcoos I.....	4.0	290	.5	21.5	8.0	8.0	38.0
Clatsop I.....	5.2	310	.0	10.1	.0	10.3	20.4
Newport II.....	2.0	320	3.0	7.0	43.5	54.0	107.5
Hoquiam II.....	2.0	340	.0	7.0	40.0	34.0	81.0

⁸ "Forests of British Columbia," by H. N. Whitford and R. D. Craig, p. 61, 1918.

⁹ "Descriptive Report of Olympic West Side Spruce," by C. J. Conover. Forest Service manuscript report, p. 13, 1918.

The underbrush, which in both the pure and mixed forests is extremely large and dense, is composed of salmonberry, huckleberry, vine maple, salal, devil's club, elderberry, and cascara, with a preponderance of the first two species. The ground cover consists chiefly of bracken, sword ferns, and moss.

The volume of spruce per acre in the virgin stand varies greatly with the proportion of species, the density of stocking, and the quality of the site. The heaviest yields are naturally produced in properly stocked stands on sites where the best growth of individual trees is made. County cruise estimates indicate that the stand of merchantable timber in what would be classed as spruce type (running all the way from 25 per cent to 65 per cent of spruce) varies from 20,000 to 100,000 feet per acre over large areas. Very much heavier, as well as lighter, stands occur in the virgin woods.

CLIMATIC AND SOIL REQUIREMENTS.

Sitka spruce is very exacting in its soil and atmospheric moisture requirements. An abundance of rainfall, frequent fogs, and temperatures moderated by proximity to the sea are the climatic characteristics of the north Pacific coastal strip where this species grows. The yearly precipitation is 75 to 150 inches or more and comes chiefly in the form of rain, well distributed throughout the year, except for about two months in midsummer. Cloudy or partly cloudy days are frequent, and weather records show an average of 240 such days in a single year at one station in the heart of the spruce region. The temperature of the region is generally mild, the annual mean ranging from 38° F. in Alaska to 53° in northern California. Extreme temperatures of 15° below zero in Alaska and 102° above in California are encountered within the range of the tree; but withal it may very readily be seen that Sitka spruce occurs only on areas that offer climatic advantages favorable for growth.

Its soil requirements, however, are not so distinctly defined, and thin, rocky soils on the slopes, pure sand along the coast, and deep, rich alluvial deposits of rivers share equally, under similar conditions of climate, in the distribution of the species; but the trees are larger and reach better development on bottom lands of moist, friable, sandy loam. It is noteworthy that in Alaska the heaviest stands of spruce and those of best quality are found on limestone soils, perhaps partly because these are the deepest and most completely decomposed. Though this species demands a very great amount of soil moisture and can grow on swampy sites, it attains its best development on soils of good drainage.

LIGHT REQUIREMENTS.

Sitka spruce, unlike other spruce, is somewhat intolerant of shade. Compared with its associates, it is less tolerant than western hemlock and western red cedar and about as tolerant as Douglas fir. Seedlings can endure heavy shade and on old burns and logged-over areas establish themselves with little difficulty under the dense cover of deciduous brush, such as salmonberry and huckleberry, and of other coniferous seedling growth; but strangely enough Sitka spruce is seldom found under the heavy canopy of a mature stand. Here temperature, not tolerance, is thought to be the governing factor, and the coolness in the mature stands prevents, whereas the warmth in the openings permits, the germination and establishment of spruce seedlings. As the tree advances in age it demands overhead light, and dies if long overtopped.

The dead side branches, which are often moss-covered stubs 2 or 3 feet long and characteristically coarse and stiff, are very persistent in young spruce. The shedding of the dead limbs and cleaning of the bole starts when the trees are about 50 years old and often is not completed for a century or more. (Pl. XII and Pl. XIII (fig. 1.))

REPRODUCTION.

SEED PRODUCTION AND DISSEMINATION.

Sitka spruce is a prolific seeder. Open-grown trees commence to bear seed at 35 years of age, and trees of all sites are vigorous producers of seed until maturity. Some seed is produced each year and heavy crops are yielded every three or four years. The cones mature in the early fall of the first year and, under normal conditions, open and release the seed within a short period afterwards. A mature tree with a full crown may produce, in a good seed year, 4 to 6 bushels of cones, which yield from 0.65¹⁰ to 1.25¹¹ pounds of clean seed. A pound of these seeds will number between 200,000 and 300,000. Because of their small size and relatively large wings they are often carried by the wind 400 feet or more from the base of the tree. Many of the seeds filter into the deep duff of the forest floor and are stored, their hard covering keeping them viable for several years. The seed has a high percentage of germination. In tests¹² of fresh commercial seed under greenhouse conditions, this amounts to 72 per cent, and is higher than the germination percentage of western hemlock, western red cedar, and Douglas fir as determined in similar tests.

¹⁰ "Sitka Spruce in Alaska," by B. E. Hoffman. Forest Service manuscript report, p. 9 1912.

¹¹ "Reforestation on the National Forests," by C. R. Tillotson. U. S. Dept. Agr. Bull. 475, p. 17, 1917.

¹² "Seeding and Planting," by J. W. Toumey, p. 122, 1916.



F-150849

FIG. 1.—VARIATION IN BASAL SWELL, ILLUSTRATED BY TREES IN LEFT AND RIGHT FOREGROUND.



F-150850

FIG. 2.—STUMPS OF MATURE TREES WHICH STARTED ON OLD WINDFALL.



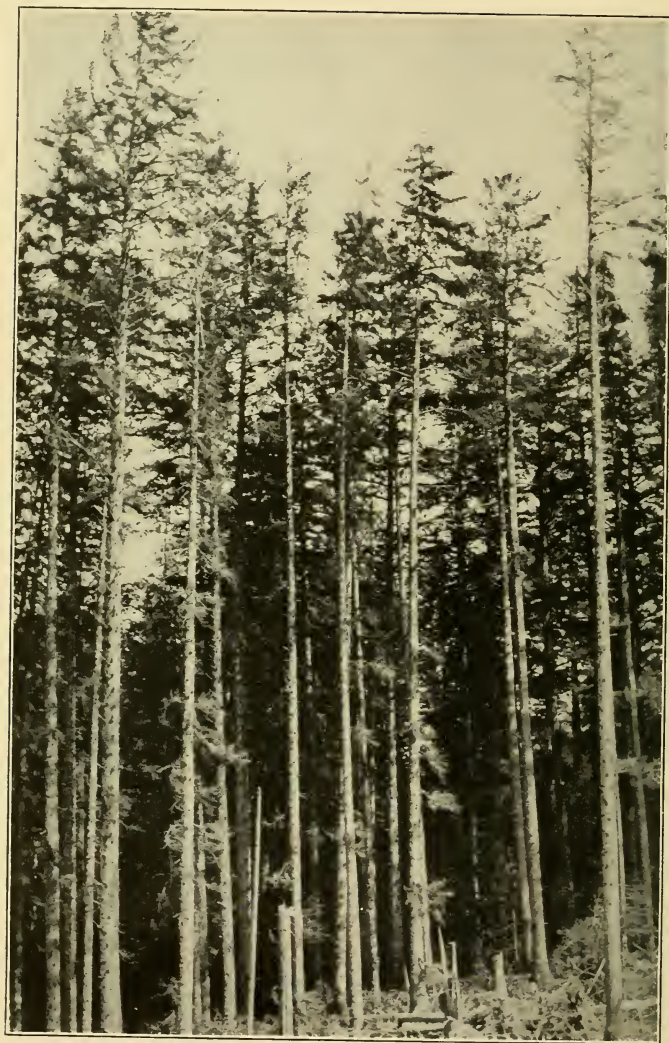
F—NLC-9

SITKA SPRUCE IN MIXTURE WITH RED ALDER AND BROADLEAF MAPLE ON RIVER BOTTOM.



F—NLC-10

HIGHLAND SPRUCE AT 1,100 FEET ELEVATION IN CLATSOP COUNTY, OREG.



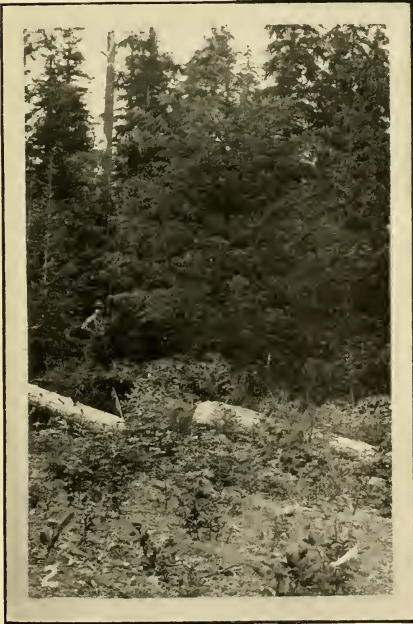
F-150834

PURE, EVEN-AGED STAND OF SITKA SPRUCE (175 YEARS) NEAR TSILTCOOS
LAKE, OREG.



F—NLC-11

FIG. 1.—A STAND OF 65-YEAR-OLD SPRUCE WITH UNCLEARED BOLES.



F—NLC-12

FIG. 2.—THRIFTY 18-YEAR-OLD SITKA SPRUCE IN OLD CLEARING.



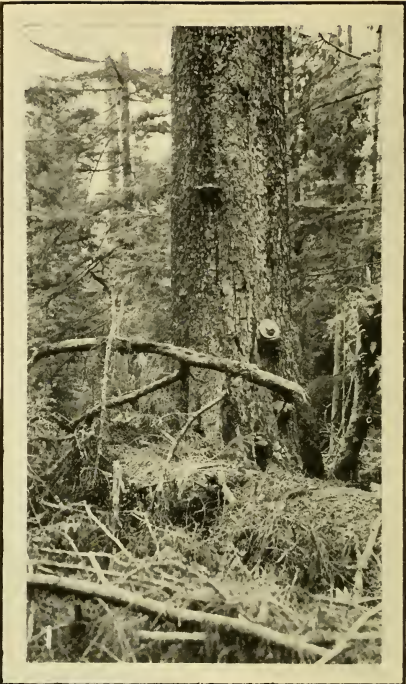
F-NIC-13

DENSE REPRODUCTION OF SITKA SPRUCE, CEDAR, AND HEMLOCK ON QUINULT BURN IN WASHINGTON.



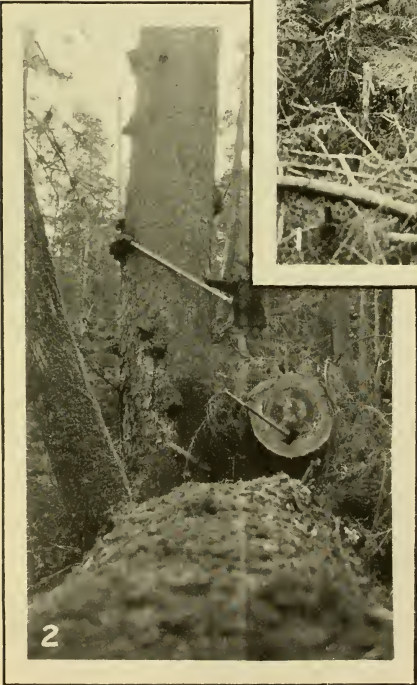
F-NLC-14

FULLY STOCKED SECOND-GROWTH STAND OF 27-YEAR-OLD SITKA SPRUCE.



F—NLC-15

FIG. 1.—FRUITING BODIES
OF FOMES PINICOLA.



F—NLC-16

FIG. 2.—FRUITING BODIES OF TRAMETES PINI.

ESTABLISHMENT OF SEEDLINGS.

Sitka spruce germinates slowly, and in this habit it is similar to other low-altitude species of the coastal region, and in contrast with Engelmann spruce and high-altitude Douglas fir, which require only a short time for germination. Similarly, Sitka spruce seedlings do not respond quickly to atmospheric warmth early in the spring, and their buds do not unfold until the season is well advanced. Were it not for this characteristic much injury to reproduction would result, for during early spring clear, warm weather in the lowlands is often followed by killing frosts.

Moisture, light, and heat are all essential for the germination and establishment of spruce seedlings; but, as moisture is abundantly supplied by rains and fogs in the region, and as the young seedlings are capable of enduring dense shade, heat is the uncertain factor. In this regard the warm exposures of old burns, clearings, and logged-over lands offer conditions more suitable for growth than elsewhere, and, as spruce can compete successfully with all other species, it establishes itself with little difficulty on these sites. In the choice of seed bed, Sitka spruce prefers loose mineral soil, but it can thrive equally well in the decayed wood of down logs and in the deep humus of the forest floor. Plate IX, figure 2, illustrates the establishment of two spruce trees on an old windfall. Because of its extreme tolerance in early youth, Sitka spruce sometimes occurs on fresh earth slides, under a temporary cover type of alder, and eventually becomes the predominating species.

Stands of reproduction in the spruce type are densely stocked. (Pls. XIV and XV.) Counts were made during the recent field study on 10 square-rod quadrates in areas of reproduction, and these counts showed that in thrifty stands under 10 years old there were 3,000 seedlings per acre, and that in stands 30 years old there were 500 trees per acre. Nearly one-quarter of the 30-year-old trees were 12 inches and over in diameter at breastheight. It was also shown that a stand of maximum density, which was 5 years old, contained 35,000 seedlings per acre. In each of these stands 50 per cent or more was spruce, and the remainder was mostly hemlock, with a few cedar and Douglas fir trees. In very dense stands Sitka spruce seedlings generally comprise only 10 to 20 per cent, but this percentage often increases as the stands become older. Under ordinary circumstances spruce is able to maintain itself and even increase notwithstanding the competition of other species. These seedlings, which are rather delicate and slender stemmed during the first few years, later develop heavy, stiff stems. They at first average nearly one-half foot in height growth per year and beyond 15 years of age increase in height at the rate of 3 feet per year.

CAUSES OF INJURY.

FUNGI.¹³

Sitka spruce, in common with other forest trees, is attacked by two broad groups of fungi—first, those reducing the annual increment; and, second, those reducing the merchantable timber.

In the first group there are two rust fungi. One of these is a broom-forming rust (*Peridermium coloradense*). The mycelium of the fungus is perennial in the twigs of the host, causing pronounced witches' brooms. As a rule, this fungus is not serious, but it may completely dwarf and deform small trees.

The other rust fungus (*Peridermium decolorans*) does not cause any deformation of the host. The mycelium confines itself to the infected needles and does not enter the twigs or branches. The parasite is usually confined to small trees of the sapling and small-pole sizes.

Another needle disease of importance is characterized by a browning of the individual needles. This fungus is *Lophodermium macrosporum* or a closely related species. Infected needles are invariably killed and drop off, but the degree of infection varies. Sometimes only occasional needles are diseased; at other times most of them may be killed. The disease usually attacks the lower branches of young trees. It has been reported as very prevalent along the lower Columbia River in Clatsop County, Oreg.

It is impossible to give an estimate of the amount of damage caused by the needle and twig diseases just mentioned. It is obvious that there must be a greater or less reduction in annual increment of the infected trees, but no exact data are available. Control measures need not be discussed, as present economic conditions preclude such work, except for nursery stock or trees of high aesthetic value.

By far the most important fungi are those which reduce the merchantable volume by attacking and destroying the heartwood of living trees.

The most serious of these on Sitka spruce is the ring-scale fungus (*Trametes pini*) which causes the common red rot or conk rot in the heartwood of living trees. In spruce the attack may be made at any point along the bole. In the split section the decayed wood has a reddish color in its early stages, and later small white sunken spots are found separated by apparently sound reddish wood. The fungus gains entrance to the heartwood of the trees principally through old branch stubs and is exceedingly destructive in mature and over-mature stands. Plates XVI (fig. 2) and XVII are illustrations of this fungus.

Next in importance is the velvet-top fungus (*Polyporus schweinitzii*), which causes a pronounced butt rot. The sporophores ap-

¹³ Prepared in collaboration with Dr. J. S. Boyce, Pathologist, Bureau of Plant Industry.

pear at the base of the tree, on the trunk in old wounds, or on the ground, coming up from decayed roots. Those on the ground have a short, thick stalk. The disease spreads both by spores blown about in the air and through the ground by means of the decayed roots. The decay which is confined to the heartwood is light reddish brown in the early stages, and pronouncedly cubical, reddish brown, crumbling to a fine powder between the fingers, and often with thin resinous crusts of mycelium in the typical stage. The rot is found in the roots and butt, and rarely extends beyond the first log. Besides the actual loss due to the volume of wood rendered unmerchantable by decay, the infected tree is frequently broken off at the base as a result of the weakening of the roots. Many large overmature trees, completely rotted at the base except for a thin layer of sapwood, are found broken off between 5 and 20 feet above ground, and their loss can be charged directly to the destructive work of this fungus.

The red-belt fungus (*Fomes pinicola*) is of equal importance with *Polyporus schweinitzii* as a butt rot in living trees; but it is also common on dead snags, old windfalls, stumps, and other débris, and thus functions as a beneficial scavenger in the forest. The fruiting bodies are usually found at the base of the tree in the flare of the roots or at scars along the lower portion of the trunk. The typical decay is light reddish-brown in color, somewhat cubical, crumbly and brittle, with white feltlike layers of mycelium occupying the cracks. Infection caused by this fungus is illustrated in Plate XVI, figure 1.

One of the most common fungi found on fallen Sitka spruce, besides the red-belt fungus, is the lacquer-top fungus (*Ganoderma oregonense*), readily recognized by the shiny, lacquerlike, reddish upper surface of the annual fruiting body. This organism has not been reported on a living spruce, but is often found on its associate, the hemlock. There are a number of other fungi of less importance which live on fallen trunks, but do not attack living trees.

Sitka spruce is much freer from decay than either western hemlock or Douglas fir, but snags and down timber decay very rapidly. The earliest infection appears in trees between 60 and 100 years of age; only a slight amount of rot is found in stands between 150 and 300 years of age, and this is confined to the butts of trees. Over 300 years, or after maturity, however, the tops commonly break off, and top rot as well as butt rot is very prevalent, becoming more marked with age. It is not unusual, however, to find trees of 400 years entirely sound at the butt and with very little decay along the trunk or in the top. In general, this species is remarkably free from decay up to 200 years of age.

The amount of resin which the wood of a tree contains, or that it is able to produce to cover any injury, affects its ability to ward off disease. Spruce, which has very little resin, is almost never able

to heal over scars or wounds along the bole; here the spores of fungi soon establish themselves and, on account of the very moist conditions in spruce stands, cause the rapid decay of much sound wood.

Advance rot spreads quickly in this species, and, though often hard to detect, it becomes very noticeable after lumber is dried. It is commonly, though not always, accompanied by a change of color in the wood, appearing as streaks of red, yellow, or green. Tests were made recently by pathologists to show the effect of different stages of decay on the strength of the wood, particularly for spruce airplane stock, but these data are not yet available for publication.

INSECTS.¹⁴

Although Sitka spruce, like other forest trees, is subject to insect attacks, it is not so susceptible as most of its associates in the forests of the Pacific coastal region. The attacks are naturally more serious in pure or nearly pure stands of Sitka spruce than in stands in which it occurs in mixture. Damage is caused by three classes of insects—bark beetles, defoliators, and borers. The first two classes attack standing timber and the last works in felled trees.

The most important insect enemies of Sitka spruce are the bark beetles, of which the most destructive is the Sitka spruce beetle (*Dendroctonus obesus*). This beetle attacks the living trees and kills them by girdling in the cambium layer. In attacking the trees the first broods enter the inner bark of the middle trunk, and those which appear later extend the infestation to the base of the trunk and even to the larger roots. This beetle also works in the inner bark of stumps, logs, and slash of felled trees. Although no extensive depredations of the Sitka spruce beetle have been found thus far, it has been reported now and then that groups of Sitka spruce have been killed by its activity. If infestations should ever become widespread it would be possible to practice control operations by cutting and barking the infested trees before the beetles emerge in the late spring. It would not be necessary to burn the bark in this work.¹⁵

From time to time Sitka spruce is subject to the attacks of such defoliators as caterpillars, sawfly larvæ, and aphids, all of which destroy the needles and may therefore occasionally kill trees over large areas. In Clatsop County, Oreg., in 1890 and 1891, Sitka spruce and western hemlock were attacked and killed over an area of thousands of acres by a caterpillar belonging to the Geometrid family. During the years 1917 to 1920 the Sitka spruce and western hemlock on several hundred thousand acres on the Tongass National

¹⁴ Prepared in collaboration with Forest Examiner A. J. Jaenicke, U. S. Forest Service.

¹⁵ For detailed information regarding control measures, see Bulletin 83, Part I, "Bark Beetles of the Genus *Dendroctonus*," by A. D. Hopkins, Bureau of Entomology, U. S. Department of Agriculture.

Forest in southeastern Alaska were defoliated by the combined activity of sawfly larvæ and caterpillars belonging to the Tineid family. Thus far only a small portion of the Sitka spruce in southeastern Alaska has been killed by this widespread defoliation.

Occasionally aphids kill the foliage of Sitka spruce. The western spruce gall louse (*Aphis abietina*) is believed by Dr. A. D. Hopkins of the Bureau of Entomology to be the aphid which caused the loss of the needles of Sitka spruce over thousands of acres of forest in 1918 in various portions of the coast region in Oregon and Washington. Fortunately the activity of this aphid was of extremely short duration, and only about 15 per cent of the infested spruce was killed. Most of this loss was confined to swamp and tideland areas in the lower Columbia River basin and the coast region and included only the poorer stands of timber. The Sitka spruce gall aphid (*Chermes cooleyi*) is found very commonly doing injury to Sitka spruce reproduction and occasionally causing its death. Large trees also are attacked, but the injury to them is rarely severe. These minute insects cause the development of conelike galls which kill the affected twigs. Infested trees of special value, such as those in parks and streets, may often, with good results, be sprayed with contact sprays like kerosene emulsion.

Fortunately the work of defoliators does not continue more than a few years when it is controlled by natural agencies. Under forest conditions control measures against this class of insects are not feasible. However, defoliators greatly increase the fire hazard on the areas on which they have been active. Nearly always the fires which followed the defoliators did more damage than the insects themselves. The reduction of the fire risk on the defoliated areas is, therefore, an important consideration in defoliator problems.

Felled timber of Sitka spruce is subject to the attacks of various wood borers. Logs cut between April and September are frequently attacked, shortly after being felled, by ambrosia beetles, sometimes called timber beetles or pinhole borers. These are small, elongate, wood-boring beetles which excavate round black tunnels, the diameter of a pencil lead, into the wood of dying trees and stumps, as well as logs. Investigations by the Bureau of Entomology in 1919 showed that species of *Gnathothrichus* and *Xyloterus* commonly attack Sitka spruce logs, as well as western hemlock and Douglas fir. These borers may penetrate the wood to a depth of from 4 to 6 inches and therefore seriously reduce the value of the sapwood, especially when Sitka spruce is being used for such special purposes as airplane stock. The logs which are cut in the late fall and winter are usually attacked in the following spring. Logs cut in the early fall are not entered that season; and, if piled loosely in

the open, they often dry sufficiently to be protected from attack the following spring. Logs placed in water are safe from further injury. Damage by these borers can be prevented almost entirely by removing the logs from the woods or placing them in water as soon as they are cut.

Larger wood borers are an important factor in the deterioration of the sapwood and heartwood of fire-killed trees and logs. During the first two summers after the death of the trees or the felling of the trees the borers are most active, and at the end of the two-year period the salvage value is usually next to nothing. If the logs are placed in water or barked within a few weeks after cutting, losses by these borers may be avoided. Logs which are loosely piled in the open soon after cutting usually escape damage because of the rapid drying out of the thin bark, which is then unattractive to the borers for the laying of eggs. Dr. J. M. Swaine, of the Canadian Entomological Branch, recommends covering the logs thickly with brush. The logs to be covered should be piled on skidways and given a very thick covering of green limbs so that the sunlight can not penetrate at all to the logs beneath.

WIND.

Sitka spruce, because of its characteristically shallow root system, can not withstand severe winds. Trees which grow on exposed situations along the coast where they encounter severe winds are windfirm, but they are also scrubby and of little use for lumber. In the virgin forests under normal conditions only the very diseased trees are likely to be windthrown, but in cut-over areas trees isolated by logging and those which border on fresh cuttings are invariably windthrown. (Pl. XVIII.) Spruce trees which have grown in dense stands never become wind-resistant, and full consideration must be given this fact before a method of cutting and a management policy are adopted for a spruce forest.

The hurricane that swept the western edge of the Olympic peninsula, Washington, in January, 1921, felled from 5 to 95 per cent of the timber on a swath 60 miles long and 20 miles wide in the heart of the spruce belt. Six billion feet or more of virgin western hemlock, Sitka spruce, Douglas fir, silver fir, and western red cedar timber was laid flat by the wind. Perhaps a billion feet of Sitka spruce in the State of Washington was windthrown in that storm. All species suffered alike regardless of their relative windfirmness.

In addition to windthrow, other damage from the elements is wrought upon spruce timber by breakage and wind-shake. The breakage consists in the shattering of the tops of overmature and decadent trees, and this permits the entrance of fungous growth,

which spreads quickly through the sound wood and renders much of the upper trunk unmerchantable. Damage from this cause is very common in trees over 300 years of age. Wind-shake is a mechanical defect resulting from heavy stresses in the butt section which are caused by the action of severe winds, and is of infrequent occurrence in large trees. This circular or radial rupture of the wood considerably reduces the value of the tree for lumber.

BURLS.

Another injury is the formation of huge burls along the trunks. This defect has been found abundantly in a limited area in Oregon. The illustrations in Plate XIX are typical examples of the defect. Its cause is uncertain, though probably analogous to similar malformations in many other species.

FIRE.

Sitka spruce is fortunate in having as its habitat a region in which there is less forest-fire hazard than in most parts of the coniferous forest regions of western North America. Frequent rains throughout the year in southeastern Alaska make fires in the virgin spruce woods there quite uncommon; farther south in Washington and Oregon there is more danger of forest fires in the short dry season. Fires in this region are apt to run in the crowns of the trees, and they do so even in the spring months when the surface litter is still too wet to burn. The moss that hangs on the branches of the hemlock, spruce, and fir trees is very inflammable and helps to carry fire. The spruce region of Oregon suffered from several very disastrous and widespread fires a few decades ago, as the "burns" of the Coast Range witness.

Sitka spruce is very susceptible to fire. This is due chiefly to its thin bark, which at stump height is only a half-inch to an inch thick. Fire-scars are uncommon in Sitka spruce, for even a very light surface fire is sufficient to kill the cambium, and the trees, thus girdled, die.

Although an individual tree of Sitka spruce is more susceptible to injury than a Douglas fir of the same size, the forest in which it grows along the coast is less subject to fire than the forest farther inland where Douglas fir predominates. Even though the danger of uncontrollable fires is less in the Coast Range than in the Cascade Range, careful fire protection in both regions is imperative.

GROWTH.

Sitka spruce is one of the most rapid-growing coniferous species in the Pacific Northwest. In keeping with the character of spruces in general, its growth during the first few years is less than that of

many other conifers; but thereafter it increases in size with great rapidity and maintains a fast growth until late in life. Its rate of growth naturally varies with the quality and the character of stand. Moisture conditions are an important factor and growth is more rapid on wet bottomland situations than on the drier slopes. The growth of Sitka spruce varies also in different parts of its range, and is more rapid in Oregon, Washington, and British Columbia than either farther south or north. Average figures on height, diameter, and volume growth are given in the tables that follow, but it is realized that these are not universally applicable. In the appendix will be found tables of growth from several different localities.

HEIGHT.

In the seedling stage the height growth of Sitka spruce is fairly rapid, but not so fast at this period as that of its associates, Douglas fir, western hemlock, and western red cedar. Table 5 shows the height growth of dominant, open-grown Sitka spruce seedlings, and is compiled from measurements taken of young trees which grew in seven different localities and sites in Oregon and Washington. Here the reproduction was sometimes found in pure stands, but more often in mixture with other species.

TABLE 5.—*Height of dominant, open-grown Sitka spruce seedlings, averaged for all sites in Oregon and Washington.*

[Based on 2,102 sectional measurements of 322 trees.]

(Curved.)

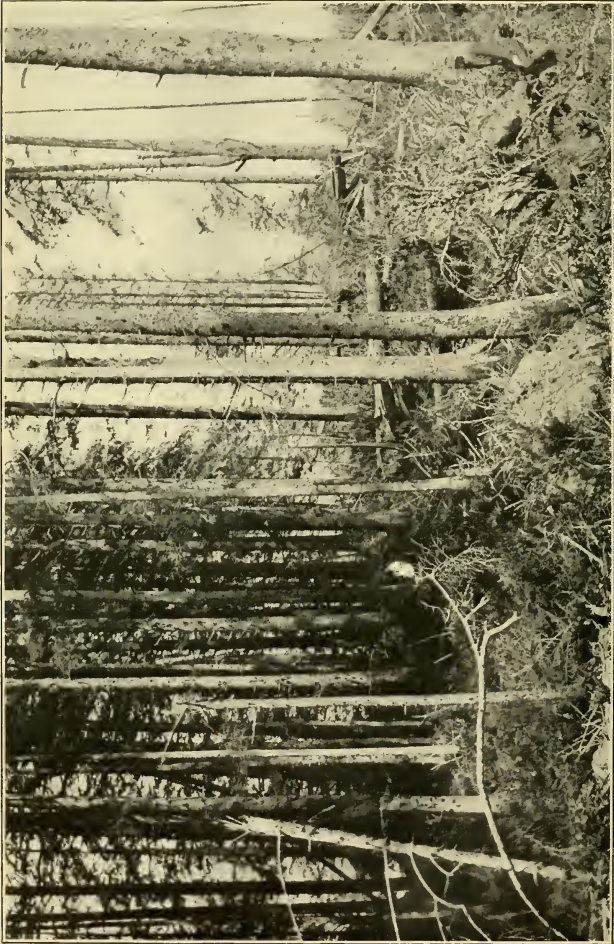
Age.	Height.	Current annual growth.	Age.	Height.	Current annual growth.
Years.	Feet.	Feet.	Years.	Feet.	Feet.
1.....	0.2	0.2	10.....	6.6	1.2
2.....	.5	.3	11.....	8.0	1.4
3.....	1.0	.5	12.....	9.8	1.8
4.....	1.6	.6	13.....	12.0	2.2
5.....	2.2	.6	14.....	14.4	2.6
6.....	2.8	.6	15.....	17.2	2.8
7.....	3.5	.7	16.....	20.2	3.0
8.....	4.4	.9	17.....	23.4	3.2
9.....	5.4	1.0			

After the early years, growth increases rapidly and is maintained at a good rate until late in life. In the sapling stage a growth of 3 feet and over a year is not unusual. At the age of 50 the average dominant tree is still growing 1.7 feet per year, and at 100 years as much as 1 foot. At these ages the height growth of spruce compares very favorably with that of Douglas fir. This comparison is made from the available growth tables for the species mentioned, under conditions representative for each species, and not by comparison of the several species growing side by side on the same site.



F-NLC-17

END VIEW OF SPRUCE LOG INFECTED WITH TRAMETES PINI.



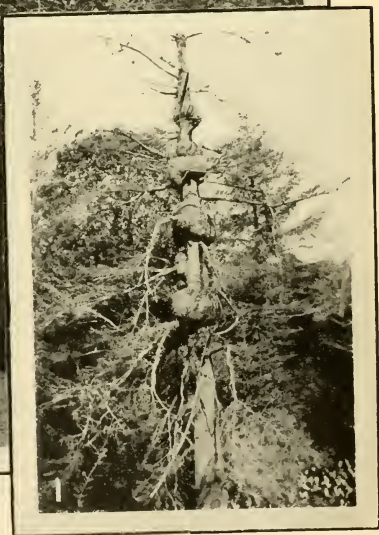
F—NLC-18

HEAVY WINDFALL DAMAGE AT EDGE OF CUTTING IN 175-YEAR-OLD STAND NEAR TSILTCOOS LAKE, OREG.



F—ZLC-20

FIG. 2.—HUGE BURLS COMMON
ALONG THE COAST NEAR
NEWPORT, OREG.



F—NLC-19

FIG. 1.—ABNORMAL GROWTH IN SPRUCE.



F-NLC-21

END SECTION OF SITKA SPRUCE LOG, SHOWING SUSTAINED DIAMETER GROWTH.

The figures given in Table 6 indicate the average total height and average annual height growth in each decade of older spruce of various ages, averaged from the measurement of 554 dominant trees. The figures are dependable for trees up to 300 years; beyond that age reliable height-growth figures are difficult to obtain, because very old spruce trees are commonly stag-headed.

TABLE 6.—Average total height at various ages, and average annual height growth in each decade of Sitka spruce on all sites in Oregon and Washington.

[Based on 1,260 sectional measurements of 554 dominant trees.] (Curved.)

Age.	Average total height.	Average annual height growth in each decade.	Age.	Average total height.	Average annual height growth in each decade.
Years.	Fect.	Fect.	Years.	Fect.	Fect.
20.....	31	2.4	220.....	224	0.3
30.....	51	2.0	230.....	226	.2
40.....	70	1.9	240.....	228	.2
50.....	87	1.7	250.....	230	.2
60.....	104	1.7	260.....	232	.2
70.....	119	1.5	270.....	233	.1
80.....	132	1.3	280.....	234	.1
90.....	144	1.2	290.....	235	.1
100.....	154	1.0	300.....	236	.1
110.....	164	1.0	310.....	236	.1—
120.....	173	.9	320.....	236	.1—
130.....	181	.8	330.....	237	.1—
140.....	188	.7	340.....	237	.1—
150.....	194	.6	350.....	237	.1—
160.....	200	.6	360.....	237	.1—
170.....	205	.5	370.....	237	.1—
180.....	210	.5	380.....	238	.1—
190.....	214	.4	390.....	238	.1—
200.....	218	.4	400.....	238	.1—
210.....	221	.3			

DIAMETER.

Diameter growth in this species is remarkably rapid and well sustained, as the figures in Table 7 indicate. In this table the figures represent the average of measurements taken of 557 dominant trees from seven localities in Oregon and Washington. Although its annual rate of diameter growth culminates at about the age of 40 years, it maintains a growth of over 3 inches per decade up to about 60 years, and thereafter for a few decades over 2 inches per decade. At the advanced age of 400 years, the data in Table 7 indicate, the diameter is still increasing at the rate of over 1 inch per decade. Exceptionally rapid diameter growth is attained on wet sites, where sometimes it may amount to three-quarters and even 1 inch annually during early years of vigorous growth. Plate XX shows the diameter growth of Sitka spruce.

TABLE 7.—Average diameter outside bark at 15 feet above ground at various ages and average annual diameter growth in each decade of Sitka spruce growing on all sites in Oregon and Washington.

[Based on measurement of 557 dominant trees.]

(Curved.)

Age.	Average diameter.	Average annual diameter growth in each decade.	Age.	Average diameter.	Average annual diameter growth in each decade.
Years.	Inches.	Inches.	Years.	Inches.	Inches.
20.....	2.0		220.....	43.4	0.14
30.....	5.6	0.36	230.....	44.8	.14
40.....	9.5	.39	240.....	46.2	.14
50.....	12.8	.33	250.....	47.5	.13
60.....	15.7	.29	260.....	48.8	.13
70.....	18.2	.25	270.....	50.1	.13
80.....	20.5	.23	280.....	51.4	.13
90.....	22.5	.20	290.....	52.7	.13
100.....	24.4	.19	300.....	54.0	.13
110.....	26.3	.19	310.....	55.3	.13
120.....	28.1	.18	320.....	56.6	.13
130.....	29.9	.18	330.....	57.8	.12
140.....	31.5	.16	340.....	59.0	.12
150.....	33.1	.16	350.....	60.2	.12
160.....	34.7	.16	360.....	61.4	.12
170.....	36.2	.15	370.....	62.5	.11
180.....	37.7	.15	380.....	63.6	.11
190.....	39.2	.15	390.....	64.7	.11
200.....	40.6	.14	400.....	65.8	.11
210.....	42.0	.14			

Diameter measurements at breast height are of little value in a Sitka spruce growth study, as this species commonly has a pronounced basal swell and its root base is usually well above the general ground level, owing to its habit of starting on down logs. For these reasons, in Forest Service timber survey work in spruce, diameters are taken at a point 1 foot above the swell; but this is a variable height and can not be used in growth studies when the relation between age and diameter is desired. In Table 7, therefore, diameters are given for a distance 15 feet above the ground and on most trees this point is above the basal swell. It must be borne in mind, however, that this uniform height above ground does not mean a uniform distance between this point and the root bases of all the trees measured. Trees which started on fallen logs 4 or 5 feet in diameter naturally have their root bases 4 or 5 feet above the ground, and the number of annual rings showing at the 15-foot point in these trees is, of course, less than at this point on trees whose root bases rest on the ground. It was found, however, that the discrepancy for all the trees measured amounted to only two years. This variation is rendered of little consequence by the rapid height growth of Sitka spruce in its sapling stage, when 3 feet per year is not an unusual growth. Another point that must be kept in mind in this connection is that it takes an average of 14 years for the seedling to reach a height of 15 feet, as shown by Table 5, and therefore a tree must be more than 14 years old before it shows diameter at this point of measurement.

VOLUME.

The volume growth of Sitka spruce is also rapid and well sustained. Table 8 indicates the average diameter, height, and volume, and the average volume growth that may be expected of dominant Sitka spruce trees in the spruce region of Oregon and Washington. The figures for diameter, height, and board-foot volume were taken from Tables 6, 7, and 11. Those for cubic-foot volume were supplied from a tree diagram in which the figures for average diameters and heights were combined with complete stem analyses of 10 dominant trees.

As indicated in this table, the periodic annual volume increment of spruce at 100 years exceeds 5 cubic feet, and at 300 years it is double this amount. The periodic annual growth continues greater than the mean annual for a long time after 300 years. At 100 years of age the volume of the entire stem without bark of dominant Sitka spruce trees approaches the high figure of 300 cubic feet, and at 200 and 300 years it exceeds 1,000 and 2,000 cubic feet respectively.

TABLE 8.—Average diameter, height, and volume and average volume growth of dominant Sitka spruce trees in Oregon and Washington.

Age.	Size.		Volume.		Annual volume growth.			
	D. o. b. at 15 ft.	Total height.	Entire stem without bark.	From stump height to top d. i. b. of 10 inches.	Periodic.	Mean.	Periodic.	Mean.
Years.	Inches.	Feet.	Cu. ft.	Bd. ft.	Cu. ft.	Cu. ft.	Bd. ft.	Bd. ft.
20.....	2.0	31	3	.....	0.15	0.15	.....	.....
40.....	9.5	70	22	.....	.9	.5	.....	.....
60.....	15.7	104	87	260	3.2	1.4	.....	4
80.....	20.5	132	175	670	4.4	2.2	20	8
100.....	24.4	154	279	1,230	5.2	2.8	28	12
120.....	28.1	173	400	1,960	6.0	3.3	36	16
140.....	31.5	188	538	2,760	6.9	3.8	40	20
160.....	34.7	200	690	3,690	7.6	4.3	46	23
180.....	37.7	210	859	4,640	8.4	4.8	47	25
200.....	40.6	218	1,036	5,660	8.8	5.2	51	28
220.....	43.4	224	1,219	6,720	9.2	5.5	53	30
240.....	46.2	228	1,417	7,800	9.9	5.9	54	32
260.....	48.8	232	1,617	8,946	10.0	6.2	57	34
280.....	51.4	234	1,818	10,040	10.0	6.5	55	36
300.....	54.2	236	2,020	11,170	10.1	6.7	56	37

YIELD.

- The yield of Sitka spruce per acre in the virgin forest varies considerably with its representation as a species in the stand, with the density of stocking, and with the quality of site. Although available data are not sufficient to furnish yield tables for the wide range

of conditions which obtain in the virgin forest, it is possible to give an idea of what may be expected under average conditions. The number of trees and the yield per acre in Table 9 are based on the averaged and curved values of twelve sample plots from one-half to 5 acres in size. On six of these plots Sitka spruce made up 88 to 100 per cent of the stand by volume; on five of them it made up 50 to 82 per cent, and on one plot it comprised 25 per cent. The plots were in essentially even-aged stands, except that the older stands contained an underwood of younger hemlock and cedar trees.

TABLE 9.—Average yield per acre of stands of Sitka spruce and associated species on good quality sites in Oregon and Washington.

(Curved)

Age.	Trees per acre.	Yield per acre.	Mean annual growth.	Age.	Trees per acre.	Yield per acre.	Mean annual growth.
<i>Years</i>		<i>Board feet</i>	<i>Board feet</i>	<i>Years</i>		<i>Board feet</i>	<i>Board feet</i>
40.....	400	29,500	734	180.....	82	140,000	778
60.....	280	54,250	904	200.....	70	144,750	724
80.....	220	75,000	975	220.....	60	148,250	674
100.....	175	99,500	995	240.....	50	151,000	629
120.....	130	115,000	958	260.....	42	153,000	588
140.....	112	126,000	900	280.....	36	154,250	551
160.....	94	134,000	838	300.....	30	155,500	518

As represented by the figures in this table, the yield of spruce stands compares well with that of Douglas fir on the best sites. Up to 90 years it makes a better yield, at 100 years it equals, and thereafter it falls a little behind Douglas fir.¹⁰ The yields of the table are those of the virgin forest; if proper methods of forest management were employed, and if the trees were thinned at regular intervals, these yields would be considerably increased. The rapid increment of Sitka spruce is especially evident when the periodic annual growth is considered, which between the ages of 40 and 60 years is 1,237 board feet.

MANAGEMENT.

Since Sitka spruce does not ordinarily grow in pure stands, but rather in intimate mixture with several other commercial trees, the principle of management which must be applied to spruce should be equally applicable to its associates—fir, hemlock, and cedar. The entire forest of which Sitka spruce forms a part must be treated uniformly. Hence the discussion of the management of spruce is interwoven with considerations of the other trees in the stand.

It has been shown that Sitka spruce is a very excellent timber tree, that its wood is superior to that of all others in the region for certain

¹⁰ Manuscript report by E. J. Hanzlik, Forest Service, Mar. 14, 1912.

purposes, that the tree has habits of growth and hardness that recommend it as a tree for the forester to favor and propagate for the forests of the future. It should be the objective, therefore, of timbermen and foresters so to manage spruce lands that they may become reforested through natural seeding, and that the new crop may contain a desirable admixture of Sitka spruce wherever this species will thrive.

Much of the land upon which the virgin forests of spruce occur has agricultural value and will be put to that use after the removal of the timber. On such lands no effort need be made by the forester or lumberman to promote a new crop to take the place of the one removed, but on all other lands this should be done.

The rapid extension of logging operations in this type makes very timely a discussion of methods of forest management which will insure continuous crops of timber.

OWNERSHIP.

The present ownership of the commercial Sitka spruce is shown in Table 10.

TABLE 10.—*Ownership of Sitka spruce timber, by classes of owners, in millions of feet, board measure.*

Ownership.	Wash- ington.	Oregon.	Cali- fornia.	Alaska.	British Co- lumbia.
Federal ¹	1,550	300	(²)	15,000- 18,000	
State.....	720	(²)	(²)		1,423
Private.....	4,205	4,074	187	(²)	12,742
Total.....	6,475	4,374	187	15,000- 18,000	14,165

¹ Including Indian reservation.

² Negligible amount.

From the above it is seen that in Alaska the Sitka spruce forests are practically all under Federal control, but that in Washington, Oregon, and California the bulk of this timber is in private ownership. The perpetuation of forests of Sitka spruce and their future welfare are largely in the hands of private owners and not under the jurisdiction of public agencies of government. Many of the holdings have been consolidated into units of 1,000 to 30,000 acres, though small properties are not uncommon. The State lands of Washington are in various-sized blocks, which in the aggregate now amount to about 10,000 acres. The Sitka spruce timberlands under Federal control in Washington lie chiefly in the Olympic National Forest and

in the Quinault Indian Reservation. In Oregon they are confined to the Siuslaw National Forest and several military and lighthouse reservations.

FIRE PROTECTION.

The most important factor in the management of the Sitka spruce type is fire protection. Without effective fire protection all other steps in forest conservation are useless. The virgin forests of the Sitka spruce type in the coastal belt are perhaps less likely to suffer from fire than the Douglas fir forests of the Cascade Range, but they are by no means immune. Systematic organized fire protection during the two or three dry summer months is essential for the safety not only of the virgin forest but also of the new crop of reproduction which follows logging. In the course of lumbering, special precautions should be taken by operators to prevent the escape of fire, for an accidental and uncontrolled fire in dry slashings may gain such headway that it will do great damage to adjoining standing timber and especially to areas of second-growth timber on older cuttings.

METHOD OF CUTTING.

Clear cutting is the method of logging universally employed in the spruce region; it is the only method practicable in these dense forests of very large trees. Moreover, Sitka spruce and western hemlock when isolated by the removal of a part of the stand are so subject to windthrow that any method of reserving seed trees of these species or of making a selection cutting is technically undesirable. Steam logging, moreover, fits in well with the requirements of the species, except so far as it increases the fire hazard, for it helps to expose the mineral soil.

SLASH DISPOSAL.

Slash disposal in the heavy forests of the Pacific coast region means the elimination of slash by broadcast burning. The objects are to reduce the fire hazard in the débris left after logging, to provide a proper seed bed for reproduction, and to retard the spread of insect and fungus diseases.

By far the most important of the above objects is to reduce the fire hazard. Since this is so the necessity for burning slash depends largely upon the fire menace of the region. Although in the spruce belt of Oregon and Washington the rainfall is abundant and fogs are frequent throughout most of the year, there are two months or more in the summer when slashings become dry, and uncontrollable fires may start and do untold damage. Because of this Sitka spruce slashings in this region should ordinarily be burned.

In Alaska, on the other hand, the danger of forest fires in the spruce belt is not great even in old cuttings because of frequent and heavy rains in the summer as well as throughout the rest of the year. Slash burning, therefore, is unnecessary and, moreover, highly undesirable, because it destroys the layer of humus and duff with which the rock is all too scantily covered in that thin-soiled country. Foresters recommend that in Alaska the slash be lopped and allowed to lie, and this is the required practice after logging on the national forests of the Territory.

If slash is to be burned in Sitka spruce stands, it is very important that it should be done the first spring or fall following logging, so that the crop of seedlings which springs up in the first growing season after cutting will not be killed by the fire. Slash burning should also be done at a time when the weather conditions are such that the fire can be held in control on the area which it is intended to burn. Further, the slash fire should be hot enough to clean up all the inflammable débris.

PROVISIONS FOR REPRODUCTION.

Studies of old cuttings indicate that Sitka spruce reproduction ordinarily follows the removal of the virgin forest, unless the area has been subjected to repeated fires. Reproduction is abundant where the slash has not been burned at all, as well as where there has been but one slash fire immediately after logging. Sitka spruce seems to be represented in the reproduction in as abundant proportions as it was in the original forest. It is apparent that this abundant reproduction following logging comes from seed which had accumulated in the ground before the virgin timber was cut, had escaped injury from fire (if the slashing was burned), and had germinated when the forest floor became exposed to the light and warmth of the sun's rays. Because of this adequate store of seed in the ground, special provisions for leaving spruce seed trees is not essential, provided only that the area is effectively safeguarded from fires after this seed germinates. As a precaution in case of an accidental fire, and as an added assurance of natural reproduction, it is well to leave occasional seed trees of such wind-firm associated species as Douglas fir, choosing those which are good seed producers. It is not ordinarily advisable to leave single seed trees of Sitka spruce, for they are too likely to be wind thrown. To secure some of this species in the next crop, reliance must be placed on the seed stored in the forest floor and released by the cutting of the virgin forest.

If natural reproduction does not restock an area adequately, it may occasionally be advisable in the interest of good management

to renew the forest artificially by seeding or by planting nursery-grown trees. This may be advisable if repeated fires have so denuded the land of seed trees and of reproduction arising from stored seed that there is no way for the natural regeneration of the stand to take place except by the slow process of migration from the surrounding timber. Methods of artificial reforestation of Sitka spruce are in general similar to those employed for Douglas fir. Occasionally successful results may be obtained from the direct sowing of seed on the denuded area, either broadcast or in specially prepared spots. This method, however, is very uncertain because of the likelihood of the seed being destroyed by birds or rodents and because of the heavy mortality which frequently occurs among the young seedlings during the first years after germination. Planting nursery-grown trees is a more dependable method, and while the initial expense may be greater than that of direct seeding, it may prove to be cheaper in the end. The use of 3-year-old transplant stock is recommended. On the better quality of sites Sitka spruce may be planted pure over relatively small areas; but, since it more commonly occurs associated with other species, a mixture of spruce with Douglas fir or hemlock is usually preferable. The composition of the former stand should largely govern the choice of species.

ROTATION.

A relatively short rotation is possible in Sitka spruce forests because of their rapid growth. Crops suitable for pulpwood might be produced on the best sites in 40 years or less, and crops for saw timber in twice that period. Information on the growth rate of the Alaskan forests is meager, but the indications are that a somewhat longer period will be required to produce timber suitable for various purposes than is needed in Oregon and Washington.

APPENDIX.

TABLE 11.—Volume table for Sitka spruce in Oregon and Washington.

This table is based on the measurement in 1914 and 1919 of 450 felled Sitka spruce (*Picea sitchensis*) trees, grown in fully stocked stands, averaged for all sites and seven localities at elevations from sea level to 1,200 feet, and from southern Oregon to northern Washington. Trees were scaled by Scribner Decimal C rule to a top diameter of 10 inches inside bark; actual height of stump was used (it averaged 8 feet); logs were scaled in 32-foot lengths and less, plus an allowance of 0.5 foot for trimming. The table was constructed by the frustum form factor method and volumes curved. Trees are classified according to their diameter outside bark at 1 foot above pronounced basal swell, which was found to average 8 feet above ground. No allowance is made for defect or breakage. Breakage in 184 trees amounted to less than 2 per cent of merchantable volume.

Diam- eter above swell.	Aver- age. ¹	Number of 32-foot logs.											Basis.	
		2	2½	3	3½	4	4½	5	5½	6	6½	7		7½
		Total height in feet.												
		112	128	142	158	173	188	202	217	231	241			
Volume in board feet in tens.														
Inches.													No. trees.	
12	5	26												
14	12	28											14	
16	19	30	41										14	
18	26	34	46	59									24	
20	40	39	53	69	83								23	
22	58	45	60	79	96	111							27	
24	83	51	69	90	109	129							31	
26	108	56	78	102	123	147	172	198					24	
28	140		88	115	139	167	195	226	255				28	
30	178		98	130	158	188	220	254	287				37	
32	219		110	144	175	210	246	283	321	358			31	
34	269		123	158	195	234	273	314	355	406			24	
36	317			174	215	258	302	346	382	437			30	
38	374			191	237	283	330	379	430	479			25	
40	431			208	259	310	362	415	469	523			31	
42	493			224	283	338	394	452	511	570			25	
44	558			239	309	369	429	491	554	619	685		13	
46	622			255	335	400	464	532	601	671	742		26	
48	692				364	433	502	576	650	726	802	881	20	
50	768				395	466	542	622	702	783	866	951	19	
52	842					503	584	668	755	842	932	1,022	18	
54	916					538	626	718	810	904	999	1,096	13	
56	998						673	769	868	968	1,069	1,173	10	
58	1,081						718	821	926	1,034	1,147	1,253	8	
60	1,169						764	875	988	1,102	1,220	1,334	5	
62	1,250						811	930	1,051	1,172	1,295	1,418	7	
64	1,334						860	987	1,115	1,246	1,373	1,505	4	
66	1,423						911	1,045	1,182	1,320	1,454	1,597	7	
68	1,514							1,107	1,252	1,397	1,539	1,690	10	
70	1,609							1,168	1,323	1,474	1,630	1,786	4	
72	1,709								1,509	1,680	1,862	2,037	7	
74	1,812								1,707	1,904	2,102	2,301	2	
76	1,919									2,148	2,374	2,586	4	
78	2,030										2,424	2,656	2	
80	2,144												2	
82	2,261												2	
84	2,381												2	
86	2,504												2	
88	2,630												2	
90	2,759												2	
													450	

¹ When trees are not tallied by number of logs, use this column.

TABLE 12.—Volume table for Sitka spruce in Behm Canal (Alaska) region.

This table is based on taper measurements, in 1917, of 131 trees, total height and length of tip of 28 trees, and total height only of 92 trees which grew near Loring, Alaska. Figures indicate merchantable volumes, scaled by Scribner Decimal C rule, and represent contents from stump height of 2 feet and up to 6 inches d. i. b. at top. They are unreliable for trees over 44 inches in diameter. The table was prepared under the direction of R. E. Kan Smith.

Diameter breast-high.	Volume.	Diameter breast-high.	Volume.
<i>Inches.</i>	<i>Board feet in tens.</i>	<i>Inches.</i>	<i>Board feet in tens.</i>
24.....	82	46.....	400
26.....	101	48.....	445
28.....	132	50.....	491
30.....	154	52.....	536
32.....	166	54.....	587
34.....	192	56.....	639
36.....	219	58.....	686
38.....	250	60.....	736
40.....	283	62.....	784
42.....	318	64.....	837
44.....	357	66.....	890

TABLE 13.—*Log volume table for Sitka spruce in Oregon and Washington.*

This table was constructed from measurements of 234 felled Sitka spruce trees in Oregon and Washington (the majority of which grew along the Hump tulips River in Washington). By means of the Scribner Decimal C rule the volume of each log and its percentage of the total merchantable volume in the tree were calculated, and these percentages were curved and applied to the merchantable volume of the average tree for each diameter class. Logs are in 32-foot lengths.

Diameter above ½ swell.		Total merch- ant- able volume.	Log volume and percentage of total volume.								Basis.
			Butt log.		Second log.		Third log.		Fourth log.		
Inches.	Bd. ft. in tens.	Bd. ft. in tens.	Per cent.	Bd. ft. in tens.	Per cent.	Bd. ft. in tens.	Per cent.	Bd. ft. in tens.	Per cent.	No. trees.	
20.....	40	23	57.8	13	33.7					2	
22.....	58	32	54.9	18	32.5					9	
24.....	83	43	52.2	26	31.6					9	
26.....	108	53	49.6	33	30.8					10	
28.....	140	66	47.1	42	30.3					8	
30.....	178	79	44.6	53	29.8	34	19.4			14	
32.....	219	93	42.6	64	29.4	42	19.5			0	
34.....	269	109	40.7	78	29.0	53	19.6			23	
36.....	317	125	39.4	91	28.7	62	19.7	55	11.0	28	
38.....	374	143	38.3	106	28.5	74	19.8	41	11.0	0	
40.....	431	161	37.5	122	28.3	86	19.9	47	11.1	85	
42.....	493	181	36.8	138	28.1	98	19.9	55	11.2	0	
44.....	558	202	37.3	156	28.0	112	20.0	63	11.3	32	
46.....	622	222	35.8	173	27.9	124	20.0	71	11.4	0	
48.....	692	245	35.4	192	27.7	139	20.1	80	11.5	13	
50.....	768	269	35.1	210	27.4	155	20.2	89	11.6	0	
52.....	842	292	34.7	229	27.2	171	20.3	98	11.7	15	
54.....	916	315	34.4	247	27.0	187	20.4	108	11.8	0	
56.....	998	340	34.1	265	26.9	204	20.5	119	11.9	14	
58.....	1,081	365	33.8	283	26.7	223	20.6	129	12.0	0	
60.....	1,169	391	33.5	309	26.5	242	20.7	141	12.1	4	
62.....	1,250	413	33.1	329	26.3	259	20.7	152	12.2	0	
64.....	1,334	437	32.8	348	26.1	277	20.8	164	12.3	4	
66.....	1,423	461	32.4	369	26.0	296	20.8	178	12.5	0	
68.....	1,514	484	32.0	392	25.9	316	20.9	191	12.6	5	
70.....	1,609	510	31.7	413	25.7	338	21.0	204	12.7	0	
75.....	1,862	575	30.9	472	25.4	395	21.2	244	13.1	4	
										23	

TABLE 14.—*Comparative diameters at breast height and above swell of Sitka spruce, based on maximum taper.*

This table is based on maximum taper measurements of 37 trees which grew in Oregon and Washington. The figures under "taper" are inches per foot of vertical distance. The diameters above swell are noted for average heights of swell.

(Curved.)

Diameter breast-high.	Diameter above swell.	Average height of swell.	Taper.	Diameter breast-high.	Diameter above swell.	Average height of swell.	Taper.
Inches.	Inches.	Feet.	Inches.	Inches.	Inches.	Feet.	Inches.
60.....	51	7	3.5	110.....	76	12	4.5
65.....	56		3.5	115.....	80		4.6
70.....	61		3.6	120.....	85		4.7
75.....	66		3.7	125.....	89		4.8
80.....	67	8	3.8	130.....	93	12	4.9
85.....	71		3.9	135.....	97		5.0
90.....	76		4.0	140.....	102		5.1
95.....	72		4.1	145.....	106		5.2
100.....	77	10	4.2				
105.....	81		4.3				

TABLE 15.¹—*Average total height of Sitka spruce on all sites in different parts of Oregon and Washington.*

(Curved.)

Age.	Tsitlecos.	Newport.	Clatsop.	Raymond.	Hoquiam.	Beaver.	Average.
	Total height in feet.						
Years.							
20.....	22	20	48	32	28	38	31
30.....	44	34	66	52	48	60	51
40.....	62	51	82	70	66	85	70
50.....	82	70	96	85	83	110	87
60.....	100	89	109	98	99	130	104
70.....	118	106	122	110	114	147	119
80.....	134	121	133	120	127	161	132
90.....	148	134	144	130	141	173	144
100.....	158	147	155	139	154	183	154
110.....	168	157	165	148	166	192	164
120.....	176	167	173	156	176	201	173
130.....	184	175	181	164	186	209	181
140.....	190	183	188	171	194	216	188
150.....	196	190	194	178	201	222	194
160.....	200	196	199	184	205	227	200
170.....	205	201	204	190	213	232	205
180.....		205	208	196	218	236	210
190.....		210	212	201	223	240	214
200.....		213	215	206	227	244	218
210.....		216	217	210	230	246	221
220.....		218	220	214	234	249	224
230.....		220	222	218	236	251	226
240.....		222	223	221	239	252	228
250.....		224	225	223	241	254	230

¹ The following is a description of the localities in which the growth measurements were taken:

Tsitlecos Lake, Lane County, Oreg.—Pure stand of even-aged second growth (175 years) on gentle slopes, at elevation of 150 to 300 feet. Soil deep, loose, sandy to sandy loam; moist but well drained.

Newport, Lincoln County, Oreg.—Three types; 130-year-old pure stand on moist, well-drained flat at 200-foot elevation in deep sandy loam; 320-year-old stand mixed with young hemlock on slopes, 300 to 350 feet above sea level in deep, well-drained sandy loam; and 300-year-old mixed stand in wet clay loam of creek bottom, 25 to 50 feet in elevation.

Clatsop, Clatsop County, Oreg.—Two types: 300-year-old pure stand on gentle slopes at altitudes of 900 to 1,100 feet, deep, moist, well-drained clay loam; 300-year-old stand in mixture with hemlock on level ground of wet clay loam at altitude of 400 feet.

Raymond, Pacific County, Wash.—Two types; small groups of even-age, varying between 110 and 440 years, on slopes of moderate pitch, well drained, deep, and of clay loam; parklike stand on poorly drained flat, at elevation of 250 to 300 feet.

Hoquiam, Grays Harbor County, Wash.—Two types; 250-year-old pure stand on moist, well-drained flat, at 400 feet elevation, in loamy soil underlain with gravel; 350-year-old stand in mixture on wet poorly drained flat, of clayey soil at same elevation.

Beaver, Clallam County, Wash.—Three hundred-year-old, pure stand in very moist, level, creek basin of rich alluvial soil at altitude of 600 feet.

TABLE 15.—Average total height of Sitka spruce, etc.—Continued.

Age.	Tsiltcoos.	Newport.	Clatsop.	Raymond.	Hoquiam.	Beaver.	Average.
Total height in feet.							
Years—Continued.							
250.....		225	226	225	242	255	232
270.....		227	227	227	243	256	233
280.....		228	228	229	244	258	234
290.....		229	229	230	245	259	235
300.....		230	230	231	246	260	236
310.....		230	231	232	246		236
320.....		231	231	232	246		236
330.....		231	231	232	247		237
340.....		231	232	233	247		237
350.....		232	232	233	247		237
360.....		232	232	233	248		237
370.....		232	232	234	248		237
380.....		232	233	234	248		238
390.....			233	234	249		238
400.....			234	234	249		238
Basis: Number of measurements.....	220	189	220	311	138	182	1,260

TABLE 16.¹—Average diameter outside bark at 15 feet above ground of Sitka spruce on all sites in different parts of Oregon and Washington.
(Curved.)

Age.	Tsiltcoos.	Newport.	Clatsop.	Raymond.	Hoquiam.	Beaver.	Average.
Diameter in inches outside bark at 15 feet.							
Years.							
20.....	1.7	2.3	3.2	1.6	2.2	3.4	2.0
30.....	5.5	6.3	7.2	4.4	5.2	8.3	5.6
40.....	9.1	10.0	11.1	7.2	8.3	12.4	9.5
50.....	13.0	13.7	14.1	9.7	11.2	16.2	12.8
60.....	16.6	16.8	16.5	12.3	13.7	19.2	15.7
70.....	19.7	19.7	18.5	14.7	15.9	21.7	18.2
80.....	22.3	22.3	20.4	16.9	18.1	23.9	20.5
90.....	24.6	24.6	22.1	19.1	20.1	25.8	22.5
100.....	26.6	26.6	24.8	21.2	22.0	27.8	24.4
110.....	28.4	28.6	25.5	23.3	23.7	29.5	26.3
120.....	30.1	30.3	27.2	25.4	25.4	31.0	28.1
130.....	31.5	31.8	28.8	27.6	27.2	32.5	29.9
140.....	32.8	33.2	30.3	29.7	28.8	33.8	31.5
150.....	34.3	34.8	32.8	31.8	30.4	35.2	33.1
160.....	35.6	36.6	33.3	34.0	32.0	36.4	34.7
170.....	36.9	37.7	34.9	36.1	33.6	37.8	36.2
180.....	38.2	39.1	36.4	38.2	35.1	39.0	37.7
190.....		40.3	37.8	40.3	36.7	40.2	39.2
200.....		41.7	39.3	42.4	38.2	41.3	40.6
210.....		43.0	40.7	44.6	39.7	42.2	42.0
220.....		44.3	41.9	46.7	41.2	43.3	43.4
230.....		45.5	43.1	48.7	42.7	44.2	44.8
240.....		46.7	44.2	50.5	44.2	45.2	46.2
250.....		47.8	45.3	52.3	45.7	46.1	47.5
260.....		48.8	46.3	54.0	47.8	47.1	48.8
270.....		49.8	47.3	55.4	48.7	48.0	50.1
280.....		50.8	48.3	56.8	50.1	48.9	51.4
290.....		51.8	49.3	58.0	51.6	49.7	52.7
300.....		52.8	50.3	59.3	52.9	50.6	54.0

¹ For description of localities see footnote to Table 15.

TABLE 16.—Average diameter outside bark at 15 feet above ground of Sitka spruce on all sites in different parts of Oregon and Washington—Continued.

Age.	Tsiltcoos.	Newport.	Clatsop.	Raymond.	Hoquiam.	Beaver.	Average.
Diameter in inches outside bark at 15 feet.							
Years—Continued.							
310.....		53.8	51.4	60.5	54.4		55.3
320.....		54.8	52.4	61.7	55.8		56.6
330.....		55.7	53.5	62.8	57.2		57.8
340.....		56.7	54.5	64.0	58.6		59.0
350.....		57.5		65.1	60.0		60.2
360.....				66.2	61.4		61.4
370.....				67.3	62.8		62.5
380.....				68.4			63.6
390.....				69.6			64.7
400.....							65.8
410.....							67.2
Basis: Number trees.....	95	78	100	133	73	78	557

TABLE 17.—Results of tests on Sitka spruce wood from Washington, in green and air-dry condition, in the form of small clear pieces.¹

[From Table 1, U. S. Dept. Agr. Bull. 556.]

Mechanical property.	Green condition.	Air-dry condition.
Number of rings per inch.....	9	9
Summerwood (per cent).....	24	24
Moisture content (per cent).....	53	8.9
Specific gravity, based on volume and weight when oven-dry.....	.37	.38
Weight per cubic foot (pounds).....	33	26
Shrinkage from green to oven-dry condition:		
Radial (per cent).....	4.5	
Tangential (per cent).....	7.4	
Static bending:		
Fiber stress at elastic limit (pounds per square inch).....	3,000	7,200
Modulus of rupture (pounds per square inch).....	5,500	11,200
Modulus of elasticity (1,000 pounds per square inch).....	1,180	1,610
Work to maximum load ² (inch pounds per cubic inch).....	6.4	10.4
Compression parallel to grain:		
Maximum crushing strength (pounds per square inch).....	2,600	5,770
Compression perpendicular to grain:		
Fiber stress at elastic limit (pounds per square inch).....	330	1,010
Shearing strength parallel to grain (pounds per square inch).....	780	1,210
Tension perpendicular to grain (pounds per square inch).....	230	
Hardness, side:		
Load required to embed 0.444-inch ball to one-half its diameter (pounds).....	370	530

¹ Test specimens were 2 inches by 2 inches in section. Bending specimens were cut 30 inches long; others were shorter, depending on test.² Work to maximum load represents the shock-absorbing ability of the wood.

LUMBER GRADES.

The following lumber grades are in use for different Sitka spruce products:¹⁷

Finish: B and Better.	Partition: B and Better.
Flooring: B and Better.	Bevel siding: A, B, C.
Ceiling: B and Better.	Wagon-box sets: B and Better.
Stepping: B and Better.	Boards and strips: Selected Common,
Battens: B and Better.	No. 1 Common.

¹⁷ For further information, see West Coast Lumberman's Association, "Rule 2: Standard Classification, Grading, and Dressing Rules for Douglas Fir, Sitka Spruce, Cedar, and Western Hemlock Products," January 22, 1922.

Dimension, plank, and small timbers:

Selected Common, Common.

Lath: Standard Grade.

Turning squares: Standard Grade.

Molding stock: Standard Grade.

Panel stock: No. 1, No. 2.

Factory lumber: Select Factory, No. 1

Shop, No. 2 Shop, 1-inch Shop Common.

Car siding and roofing: B and Better.

Ladder stock: Special Grade.

Cut-up sash and door stock: No. 1, No. 2.

Piano posts: Special Grade.

Sounding-board stock: Special Grade.

Box lumber: No. 1, No. 2, No. 3.

Airplane stock: Special Grade.

Flitches: Special Grade.

LOG GRADES IN BRITISH COLUMBIA.¹⁸

SPRUCE, PINE, AND COTTONWOOD.

No. 1: Logs 12 feet and over in length, 30 inches in diameter and over, up to 32 feet long, 24 inches if over 32 feet long, reasonably straight, clear, free from such defects as would impair the value for clear lumber.

not No. 2: Logs less than 14 inches in diameter and not over 24 feet long, or not less than 12 inches in diameter and over 24 feet long, sound, reasonably straight, free from rotten knots or bunch knots, and the grain straight enough to insure strength.

No. 3: Logs having visible defects, such as bad crooks, bad knots, or other defects that would lower the grade of lumber below merchantable.

Cull: Logs lower in grade than No. 3 will be classed as culls.

¹⁸ "Forests of British Columbia," by H. N. Whitford and R. D. Craig, p. 170, 1918.

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Contribution from the Bureau of Entomology

L. O. HOWARD, Chief



Washington, D. C.



June 21, 1922

CURCULIOS THAT ATTACK THE YOUNG FRUITS AND SHOOTS OF WALNUT AND HICKORY.

By FRED E. BROOKS,

Entomologist, Fruit Insect Investigations.

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INTRODUCTION.

Several species of snout-beetles nearly related to the common plum curculio (*Conotrachelus nenuphar* Hbst.) attack the immature fruits, tender shoots, and leaf petioles of walnut and hickory. Four such species are discussed herein, all belonging to the genus *Conotrachelus* and all having evidently at times been confused under the one most familiar species, *Conotrachelus juglandis* Lec. The four species throughout the several stages of their development resemble one another closely in appearance, habits, and seasonal activities, except that they select different food plants or have different methods of attack.

Several members of this group attack acorns and there are also several species of an allied group of snout-beetles (genus *Balaninus*) the larvæ of which feed in mature, or nearly mature, chestnuts, hickory nuts, hazelnuts, and acorns. These are not dealt with in this bulletin.

THE BUTTERNUT CURCULIO.¹

The butternut curculio has been known commonly in the past either as the "walnut weevil" or "walnut curculio." It would seem that for the members of this group whose larvæ feed in immature nuts the term "curculio" is to be preferred in order to disassociate them in the popular mind from members of the *Balaninus* group, which have long been known as "nut weevils." The other part of the name is here restricted to "butternut" for the reason that this species appears to confine its attacks almost exclusively to our native butternut (*Juglans cinerea*) and to introduced walnuts of the butternut type. There is a very similar but distinct species to which the name "walnut curculio" could be applied with equal appropriateness. In rearing several hundred specimens the writer has failed to obtain a single individual of *C. juglandis* from infested young black walnuts (*Juglans nigra*), the species commonly attacking black walnuts being *Conotrachelus retentus* Say, described on pages 7-11. One beetle of *C. retentus* was found among a lot of beetles of *C. juglandis* reared from butternuts, and it is possible that with both species of insect there is occasional interchange of hosts.

The butternut curculio also attacks and injures seriously the fruit and small branches of various species of introduced walnuts, being especially destructive to the Japanese walnuts (*J. sieboldiana* and *J. cordiformis*) which are of the butternut type. (Pl. II, *D*; Pl. III, *B*.)

DISTRIBUTION.

The known range of the butternut curculio extends from the Provinces of Ontario and Quebec, Canada, south through the New England States, Wisconsin, Iowa, and Kansas to Alabama and Georgia. Britton and Kirk² record it from 20 States within the boundary just given. The distribution of the insect follows rather closely the natural range of the butternut, which is its favorite native food plant. Throughout the general range of the insect there are evidently many localities, even where host trees abound, in which it is very rarely found. In many other localities it is abundant and destructive.

FOOD PLANTS.

Britton and Kirk² give the food plants in the order of preference shown as follows: *Juglans cordiformis*, *J. sieboldiana*, *J. cinerea*, *J. regia*, *J. nigra*, and *J. mandshurica*. They quote Dr. Robert T. Mor-

¹ *Conotrachelus juglandis* Lec.; suborder Rhynchophora, family Curculionidae, tribe Cryptorhynchini.

² BRITTON, W. E., and KIRK, H. B. LIFE HISTORY AND HABITS OF THE WALNUT WEEVIL OR CURCULIO. In 12th Ann. Rept. State Ent. Conn., p. 240-253. 1912.

ris, a nut grower, of New York City and Stamford, Conn., as stating that he has observed this curculio on various species of hickory. Blatchley and Leng³ record the species as "occurring on walnut, butternut, and hickory, the larvæ breeding in the green fruit."

The present writer has found this curculio attacking extensively the fruit of our native butternut (*J. cinerea*) and the shoots and leaf petioles of the Japanese walnuts (*J. sieboldiana* and *J. cordiformis*). It was found less frequently feeding and ovipositing in the shoots of the native butternut and the fruits of the Japanese walnuts. Several beetles were found in September on the branches of a young tree of *Juglans cathayensis* growing in Arnold Arboretum, at Boston, Mass., and there were evidences of serious injury to the branches made earlier in the season by the larvæ. Similar although less extensive injury was noted on a tree of the same species growing in one of the parks of Rochester, N. Y.

NATURE AND EXTENT OF INJURY.

The injury inflicted by this insect consists of feeding punctures made by the adults in the nuts, tender tips, and leaf petioles and the burrows of the larvæ in the nuts and new growth of various species of walnuts. Extensive injury has been reported from Connecticut,⁴ where young transplanted trees and trees in the nursery row have been partially or entirely killed by the larvæ working in the branches. The most serious loss of this kind has been to the Japanese walnuts, although trees of the Persian walnut have suffered to some extent. Britton and Kirk⁵ describe infestation in one nursery as follows:

In a nursery at New Canaan [Conn.], about the middle of September, Mr. Kirk noticed a row containing about 265 trees of *Juglans sieboldiana* on all of which the larvæ were tunneling in the new growth. An adjoining row of about the same number of *J. regia* trees was only slightly attacked, and another adjoining row containing about 400 trees of black walnut, *J. nigra*, were uninfested. Several hundred other trees of *J. sieboldiana* in another part of the same nursery were badly infested, not a single tree escaping. Here, also, was noticed the fall attack of the adults at the base of the leaf petioles, and two adults were collected.

During the present investigation the writer has observed serious injury to young trees of *J. sieboldiana*, *J. cordiformis*, and *J. cathayensis* in Massachusetts, Connecticut, and New York. Southward, particularly in Maryland and West Virginia, extensive attacks upon the fruit of the native butternut occur regularly. Many cases have been observed in which 50 per cent or more of the nuts dropped from trees prematurely on account of injury by the curculio larvæ, the percentage of loss being greatest in years of light crops. Farther

³ BLATCHLEY, W. S., and LENG, C. W. RHYNCHOPHORA OR WEEVILS OF NORTHEASTERN AMERICA, p. 469. 1916.

⁴ BRITTON, W. E., and KIRK, H. B. Op. cit.

north attacks upon the fruit of the native butternut seem less extensive, although at least a few infested nuts can usually be found upon or beneath any bearing tree. A case of slight injury to the nuts was found in 1920 in Jefferson County, N. Y. At nearly the same time about 20 bearing butternut trees were examined along the St. Lawrence River, in St. Lawrence County, N. Y., and not a trace of the insect found. Beetles were reared from both shoots and fruit of *J. sieboldiana* collected at Lockport, N. Y., and larvæ were abundant in butternuts collected at Lake Winnepesaukee, in central New Hampshire.

Occasionally the larvæ are found boring in young shoots of butternut at French Creek, W. Va., oviposition evidently taking place in the tips of these shoots before the fruit is large enough to be attacked. On July 2, 1920, in the last-named locality, 60 half-grown butternuts were picked at random from the lower branches of one tree. Of these 60 nuts 48 contained egg punctures of the curculio and 12 were sound. A number of nearly full-grown larvæ were also found boring in the terminal shoots and leaf petioles. These larvæ averaged larger than those in the nuts, indicating, as in numerous other observations made, that eggs are first laid in the shoots.

LIFE HISTORY.

The butternut curculio has but one generation annually, and, like other members of the genus, passes the winter in the adult stage. In West Virginia oviposition begins in May and continues practically all summer, apparently reaching its maximum the last of June or the first of July.

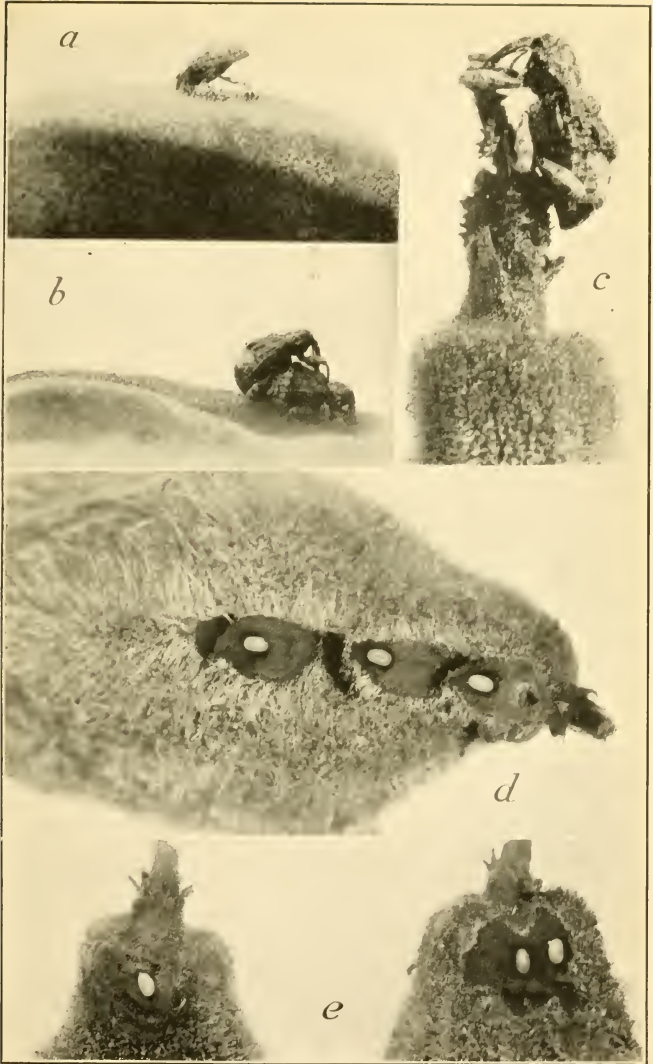
EGG.

The egg is oblong, oval, creamy white, with the surface like ground glass. (Pl. I, *D* and *E*; Pl. II, *A*, *B*, and *C*.) Three measured on July 2, 1920, were uniformly 1 mm. long by 0.6 mm. wide. Two measured on June 7, of the same year, were 0.9 mm. long by 0.6 mm. wide. Britton and Kirk⁵ give the following dimensions: Length, 0.95 mm.; thickness, 0.57 mm. Most of the eggs hatch in from 8 to 10 days, although the period may extend to 15 days.

LARVA.

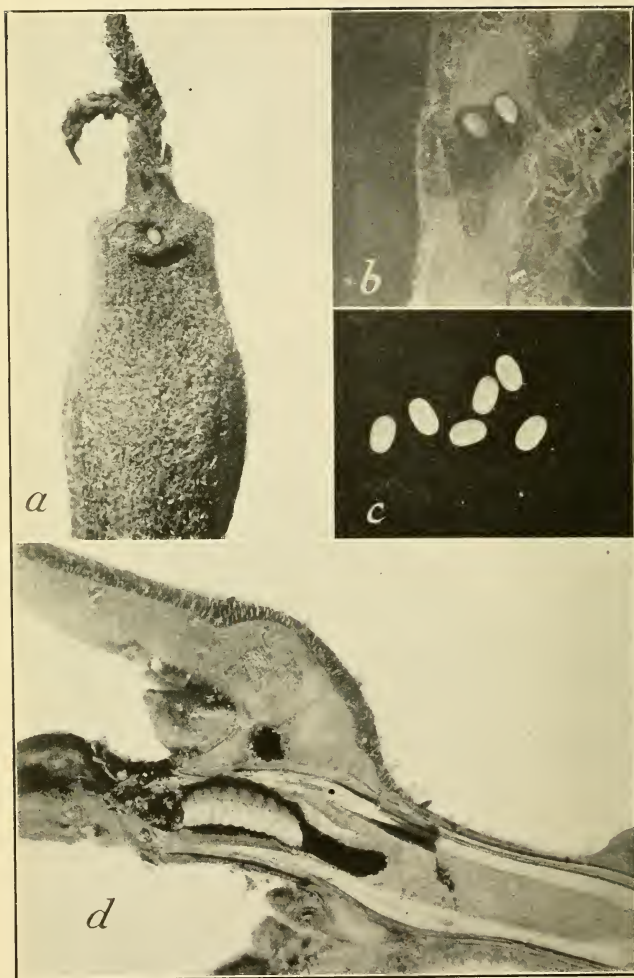
The larvæ are whitish, or dirty white, with brown head and blackish mandibles. (Pl. II, *D*; Pl. III, *A* and *B*.) The length is 12 to 13 mm. and the thickness 3 mm. Feeding in the nuts and shoots, they become full grown in four or five weeks and then enter the ground to pupate. Nuts that are attacked when very small usually furnish

⁵ BRITTON, W. E., and KIRK, H. B. Op. cit.



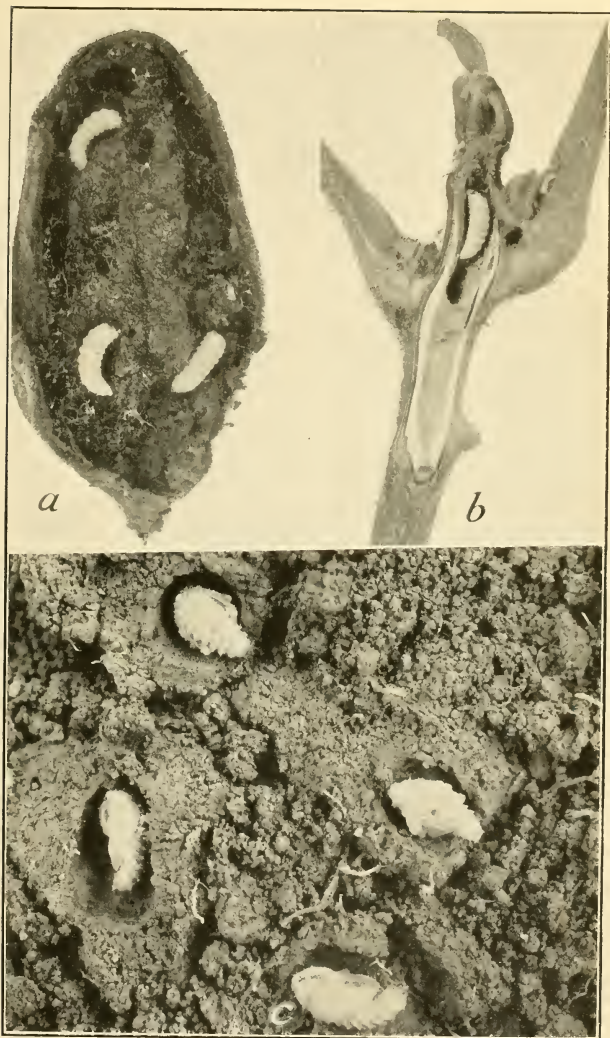
THE BUTTERNUT CURCULIO.

a, Adult curculio excavating egg chamber in butternut; *b*, adult female excavating egg chamber accompanied by male; *c*, curculio on tip of young butternut, a favorite resting place; *d*, eggs in young butternut exposed by cutting away the skin; *e*, eggs near tip of butternuts, a favorite place for oviposition while the nuts are small. All enlarged.



THE BUTTERNUT CURCULIO.

a, Egg and egg-punctures near tip of young butternut, egg exposed by removing skin of nut; *b*, eggs in shoot of Japanese walnut; *c*, eggs; *d*, larva boring in pith of Japanese walnut shoot. All enlarged.



THE BUTTERNUT CURCULIO.

a, Larvæ in husk of butternut; *b*, larva in shoot of Japanese walnut; *c*, pupæ within pupal cells in the ground. All slightly enlarged.

enough food to bring only one larva to maturity, but nuts that become infested when larger may contain from four to six larvæ which reach full growth. After leaving their feeding places preparatory to pupation the larvæ are active and crawl rapidly. When exposed to the light they have a habit of bending and catching the anal tip under the jaws and then releasing the tip with a jerk, sometimes throwing themselves in this way a distance equal to the length of the body. The larvæ issue chiefly in the early morning hours and enter the soil as quickly thereafter as possible. In West Virginia larvæ began to issue from butternuts on July 18 and continued to appear until September 4. Table 1 shows the rate of emergence.

TABLE 1.—*Time and rate of emergence of larvæ of the butternut curculio from half a bushel of butternuts at French Creek, W. Va., during the season of 1920.*

Date.	Num- ber of larvæ.	Date.	Num- ber of larvæ.	Date.	Num- ber of larvæ.
July 18.....	3	Aug. 5.....	4	Aug. 23.....	9
19.....	0	6.....	2	24.....	3
20.....	16	7.....	5	25.....	1
21.....	0	8.....	1	26.....	1
22.....	9	9.....	8	27.....	0
23.....	1	10.....	4	28.....	0
24.....	5	11.....	5	29.....	0
25.....	11	12.....	2	30.....	0
26.....	153	13.....	2	31.....	0
27.....	22	14.....	7	Sept. 1.....	0
28.....	10	15.....	4	2.....	3
29.....	2	16.....	0	3.....	0
30.....	1	17.....	0	4.....	4
31.....	0	18.....	4	5.....	0
Aug. 1.....	13	19.....	1		
2.....	97	20.....	0	Total.....	464
3.....	40	21.....	1		
4.....	1	22.....	9		

As set forth in Table 1, 464 larvæ issued from half a bushel of infested butternuts over a period of 49 days. It is an interesting fact that emergence was much more rapid during cool than warm weather. For example, on the mornings of July 26 and August 2, the dates of maximum emergence of the larvæ, the temperature registered, respectively, 46° and 54° F. More than half the entire number of larvæ issued on these two mornings of unusual cold.

PUPA.

The pupa (Pl. III, C) is creamy white, the color deepening and the eyes becoming dark as the adult stage is approached. The length averages 10 mm. and the thickness 5 mm. The entire ventral surface is sparsely covered with short, stiff hairs. The pupa occupies a smooth-walled cell from 1 to 3 inches below the surface of the ground. Nearly a month is spent beneath the ground by the insect in the pre-pupa, pupa, and young adult stages and then it emerges as a fully developed beetle and seeks the branches of a host tree.

ADULT.

The beetle (Pl. I, *A*, *B*, and *C*) resembles very closely the common plum curculio, being brownish gray with a variable, whitish, curved line on each side of the thorax and a broad whitish band behind the middle of the elytra. The back is marked with prominent humps and ridges and is covered with short gray and whitish pubescence. The strong curved beak is nearly half as long as the body, and the body, exclusive of the beak, averages about 7 mm. in length. The general appearance of the beetle is rough and angular.

The young beetles issue from the soil in late summer and early autumn, 64 individuals issuing in West Virginia between August 17 and September 6. Of these beetles the maximum daily emergence of 13 took place on August 27. A few beetles continued to come from earth in rearing jars up to the middle of October. These young beetles reach the trees before those of the parent generation have all died, and, like them, feed sufficiently in the autumn on the surface of terminal shoots and leaf petioles to suggest their destruction with arsenical sprays in September or early October. The beetles go into hibernation, probably in litter on the ground, with the approach of freezing weather.

The beetles issue from hibernation in the spring at about the time walnut trees come into bloom and resort at once to their host trees. They may at this time be jarred in abundance from butternut trees, a few having been taken in West Virginia by jarring black walnut and hickory trees growing near butternut trees. With very few exceptions, however, the species jarred from black walnut at this season of the year has been *C. retentus* and those from hickory *C. aratus*. This usually holds good even where the three kinds of trees grow in close proximity.

Feeding begins in a limited way soon after the beetles appear on the trees, the food consisting of stem and leaf tissues of the new growth. The feeding marks in the stems are in the form of irregular pits reaching through the bark and are sometimes extensive enough to cause the leaves and tips to droop and die. Oviposition soon begins, the first eggs being laid in the new growth which forms before the fruit is large enough to be attacked. In the native butternut most of the eggs are withheld until the nuts are large enough to receive them, this being when the nuts are about an inch long. In young and tender nuts practically all the eggs are placed in crescent-shaped marks eaten into the husk near the blossom end. (Pl. I, *E*; Pl. II, *A*.) By means of an extrusive ovipositor the egg is thrust into a small pocket excavated beneath the tongue of skin on the concave side of the crescent. The beetles are often found resting upon the remnants of the blossom that project from the tip of the young

nuts (Pl. I, C), and in excavating the egg chamber in such nuts the female beetle takes her position on this withered part of the blossom, and, with her head pointing toward the nut, proceeds to excavate the crescent-shaped egg chamber. On account of her method of work the concave side of the crescent faces the tip. (Pl. II, A.) It is not unusual to find a young butternut with a row of these crescent marks completely encircling the blossom end.

As the nuts develop and the husk becomes tougher the beetle changes somewhat her method of procedure, and instead of cutting out the crescents for her eggs, places them in simple cavities gouged into the side of the nut through small openings in the skin. Such cavities are usually arranged in groups, the skin about the wounds being marked by dark stains from slight exudations of juice and from excrement voided by the beetle during the excavating process. These groups of punctures often contain half a dozen eggs each, one having been found by the writer which contained 11.

NATURAL ENEMIES.

During this investigation two species of dipterous parasites have been reared in West Virginia from larvæ of the butternut curculio. These have been determined by Dr. J. M. Aldrich, of the United States National Museum, as *Chaetochlorops inquilina* Coq. and *Cholomyia longipes* Fab. Both species are rather abundant, the first-named, especially, rendering good service in holding the curculio in check. Other investigators have reared the following species from this host: *Metadexia basalis* G.-T., *Cholomyia inaequipes* Bigot, *Myiophasia aenea* Wied., and *Sigalphus curculionis* Fitch.

THE BLACK-WALNUT CURCULIO.*

In June, 1919, the ground beneath bearing black walnut trees (*Juglans nigra*) at French Creek, W. Va., was found to be strewn thickly with young nuts the size of small marbles. Examination showed that each nut contained a single dirty-white larva half an inch or less in length. A quantity of the nuts were collected and placed in rearing jars with the expectation that in due time beetles of *Conotrachelus juglandis* would be reared therefrom. When the beetles appeared, however, they were slightly different from *C. juglandis*, and specimens submitted to Mr. E. A. Schwarz, of the United States Department of Agriculture, were determined as *Conotrachelus retentus* Say, a species the habits of which had hitherto been practically unknown. Further observations proved that this species attacks commonly the young fruits of black walnut in many localities in the eastern part of this country.

* *Conotrachelus retentus* Say; suborder Rhynchophora, family Curculionidae, tribe Cryptorhynchini.

DISTRIBUTION.

This species was described and named nearly a century ago by Thomas Say.⁷ Since Say's description was published entomologists have from time to time collected specimens of the beetle, but no data on the feeding habits of the species have found their way into print. There are records of beetles being collected at Allegheny, Pa., Topeka, Kans., Mendenhall, Miss., and Haulover, Fla. During the present investigation the writer has collected the species at Harrisburg and York, Pa.; Hagerstown, Cumberland, and New Windsor, Md.; Morgantown and French Creek, W. Va.; Fincastle, Gala, Lick Run, Marion, McDowell, Oak Ridge, Pulaski, and Radford, Va.; and Black Mountain and Hickory, N. C.

FOOD PLANTS.

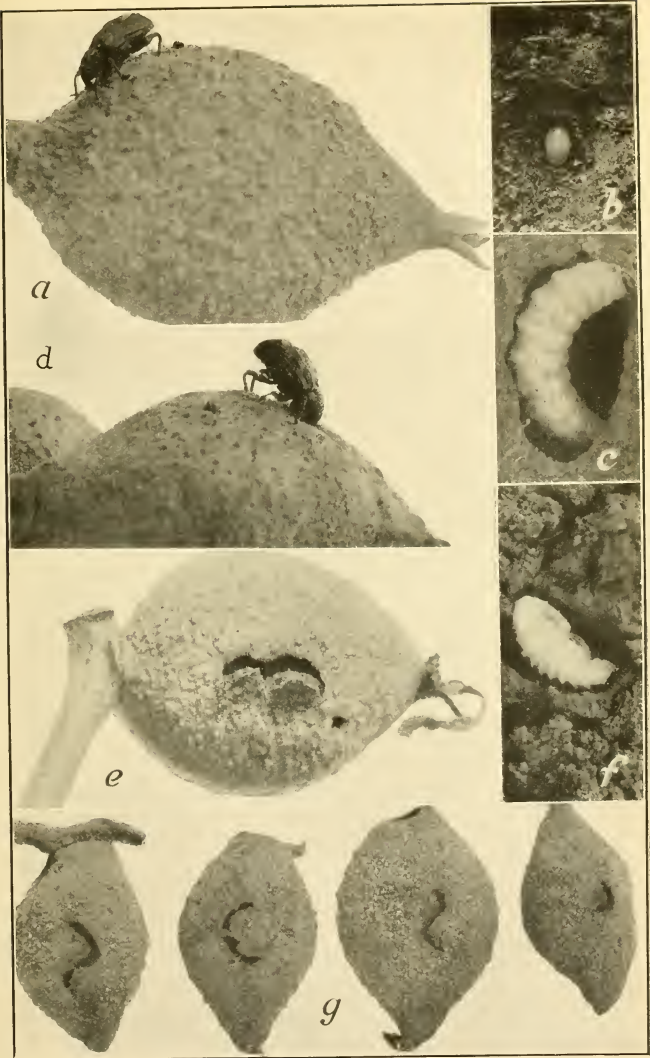
No food plants of this curculio seem to be known other than the black walnut (*Juglans nigra*) and butternut (*J. cinerea*). Of these two, the black walnut is much preferred, only one beetle of the species having been obtained in extensive rearings from butternut. Hamilton records taking the beetles by beating red oak sprouts, and the present writer has collected them from hickory trees growing close to black walnut. The occurrence of the beetles on both the red oak and hickory was probably accidental.

NATURE AND EXTENT OF INJURY.

Except for its different food plant, this species corresponds very closely in all its activities as well as in appearance with the butternut curculio. The adults feed on the tender shoots and leaf petioles and make oviposition scars and feeding punctures in young black walnuts similar to those made in butternuts by the other species. The larvæ develop in young black walnuts and cause the nuts to drop, usually before they are half grown. The larvæ are occasionally, but rarely, found burrowing in the tender shoots of black walnut.

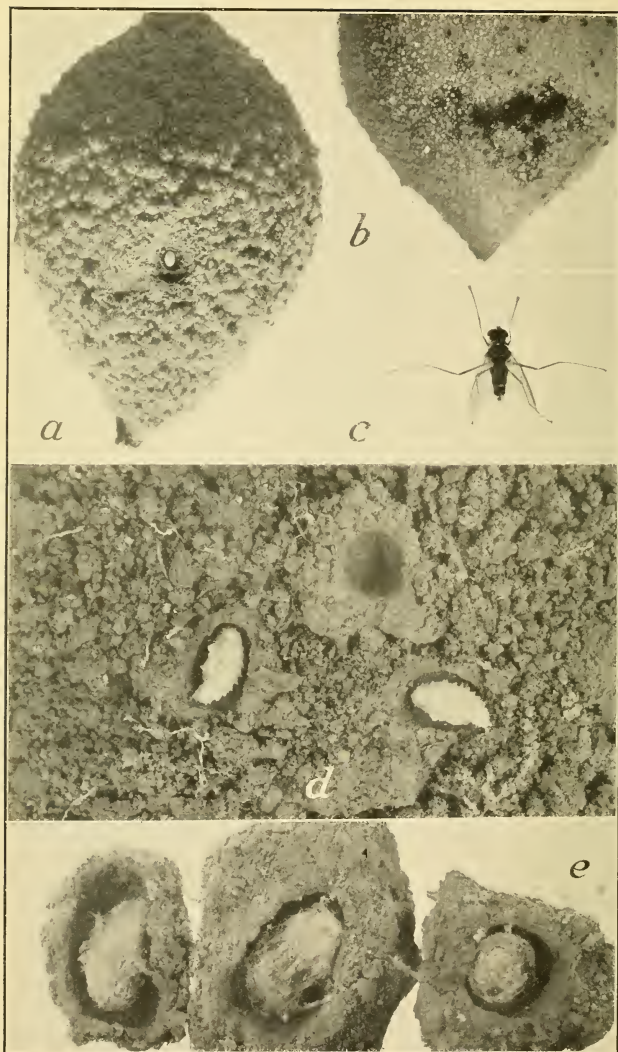
In seasons when black walnut trees are bearing a light crop of nuts a large percentage of the crop may become infested and drop, but in years of heavy fruitage the curculios do no more than to effect an unimportant thinning of the nuts. The following notes of field observations indicate degrees of infestation such as were frequently noted. On June 15, 1920, 17 newly set black walnuts were picked from the lower branches of a tree growing in a parklike woods near Cumberland, Md. Of these 17 nuts, 16 contained curculio egg punctures and the other a feeding puncture. On the 16th of the same month 50 per cent of the nuts on trees growing along the highway at New Windsor, Md., were found infested. At French

⁷ SAY, THOMAS. ENTOMOLOGY OF NORTH AMERICA. (Leconte ed.) v. 1, p. 295. 1859.



THE BLACK-WALNUT CURCULIO.

a and *d*, Female beetles excavating egg chamber in young black walnuts; *b*, egg; *c*, larva constructing pupal cell in the ground; *e*, egg punctures in young walnut; *f*, pupa; *g*, egg punctures in walnuts.



THE BLACK-WALNUT CURCULIO.

a, Egg in natural position exposed by removing skin of young black walnut; *b*, group of egg punctures in half-grown black walnut; *c*, parasitic fly *Cholomyia longipes*; *d*, pupæ within pupal cells in earth; *e*, cocoons of the parasite *Thersilochus conotrachei* occupying the pupal cells of the curculio after killing and devouring the host larvæ. All enlarged.

Creek, W. Va., 400 young nuts were gathered at random from the lower branches of four black walnut trees growing in a pasture field. Of this lot of nuts 289 contained 466 egg punctures and the remaining 111 were sound. In another instance in the locality last mentioned 1,447 infested nuts dropped from one tree during the season.

So far as observations have been made, the black walnut curculio seems much more abundant and injurious in the latitude of Maryland and West Virginia than within the range of the black walnut farther to the north. In the vicinities of Trenton, N. J., Lancaster, Pa., Rochester and Lockport, N. Y., and Wallingford, Conn., a number of bearing black walnut trees were examined without finding any evidences of the presence of the curculio. Locality records by various entomologists and observations made during the present investigation indicate a southern rather than a northern range for this species.

LIFE HISTORY.

EGG.

The egg (Pl. IV, *B*; Pl. V, *A*) is oval, oblong, creamy white, surface delicately granulose, 1 mm. long by 0.7 mm. wide. Eggs that are deposited in young, tender nuts are placed beneath the flap of skin within a crescent-shaped puncture eaten out of the side of the nut (Pl. IV, *E*, *G*). In the more solid husk of half-grown nuts the eggs are inserted in less elaborate punctures which resemble pin pricks and extend directly into the husk. (Pl. V, *B*.) These simple egg punctures in the more nearly mature nuts are usually formed in groups of from three to six on the side of the nut.

About a dozen eggs deposited in nuts on the trees on July 15 hatched on the morning of July 22 and an equal number deposited on July 16 hatched on July 23, an incubation period in both cases of 7 days under natural conditions. Two other lots of eggs laid and kept in an open insectary hatched in five and six days, respectively. In West Virginia oviposition begins normally during the last days of May and continues through June and most of July.

LARVA.

The larva (Pl. IV, *C*) is creamy white with brown head, legless, and fusiform. It assumes naturally a curved position and is sparsely clothed with short, stiff hairs. The length is 11 mm. and the thickness 3 mm. As soon as hatched it begins to feed from the side of the oviposition wound, and, in young nuts, soon devours the whole interior. In the older nuts feeding is done chiefly in the husk. The infested nut adheres to the branch until the larva is at least half grown, and then drops, the larva continuing to feed while the nut

dries and hardens on the ground. When the larva is full grown it ceases feeding, assumes a clearer cream color, and, after a period of a week or two of inactivity within the nut, cuts its way out through the shell and enters the ground to a depth of from 2 to 4 inches to pupate. Larvæ may be found in the nuts from early in June until late in September. In one lot of 805 larvæ which issued from infested black walnuts kept in rearing jars the first larva left the nut on July 14 and the last on September 21. These larvæ, like those of the butternut curculio, chiefly issued early in the morning and the largest numbers always in cool weather. In small green nuts only one larva matures to the nut, but two or three larvæ may develop together in a large nut. Apparently where several larvæ hatch and begin feeding in a small nut one individual always kills and devours the others. In two or three instances one larva was found killing and eating its fellow. On entering the ground the larva seeks a place where the soil is solid and fashions a smooth-walled cell (Pl. IV, *C*; Pl. V, *D*), where it rests for several days before pupating.

PUPA.

The pupa (Pl. IV, *F*; Pl. V, *D*) is white and is about 9 mm. long by 3 mm. thick. The abdomen, thorax, and wing pads are covered thinly with short, stiff hairs, these hairs being shortest on the wing pads. The pupa occupies an unlined earthen cell from 2 to 4 inches beneath the surface of the ground. The pupa stage covers a period of from two to three weeks.

ADULT.

The mature beetle (Pl. IV, *A* and *B*) is dull reddish-brown and covered with grayish pubescence. There is a lighter colored, indistinct, broad band behind the middle of the elytra and a vague, broken line of the same lighter shade on each side of the thorax. The snout is half as long as the body and the back is ridged and punctured. The length averages from 6 to 7 mm. This beetle in size and general shape resembles very closely the butternut curculio but its color markings and elytral sculpturing are less pronounced.

The newly developed beetles begin issuing from the ground in August; the first specimens were obtained in this investigation on August 7. In one rearing cage 75 beetles came from the ground between August 13 and September 2, the maximum emergence taking place from August 24 to 29.

In late summer and early autumn the young beetles may be found on their host trees, where they apparently feed on the leaf petioles before seeking their hibernation quarters. The beetles live through the winter, probably hidden in the duff at the surface of the ground,

and resume activity in the spring in time to be on black walnut trees when the male catkins of the walnut are fully developed. As soon as the leaves and tender shoots appear the beetles attack them, sometimes feeding rather extensively. Soon thereafter they begin egg-laying in the young fruit. There is considerable variation in the time the fruit sets on individual trees of the black walnut in any locality and the beetles collect on the trees where the developing nutlets are at the stage just to their liking. This is immediately after the female catkins on the point of the nut are beginning to wither. Most of the eggs are deposited in nuts at this stage of their development, although the beetles continue to oviposit to some extent in nuts that are larger.

The beetles live normally throughout most of the summer and oviposit over a period of at least two months. Several overwintering beetles confined in screen cages placed over walnut branches on the trees lived until the last of August. It is thus possible in late summer to find the parent beetles and their mature offspring together on the trees.

NATURAL ENEMIES.

At least five species of insect parasites were found attacking the black walnut curculio in its larva and pupa stages. Three species of parasitic flies, determined by Dr. J. M. Aldrich as *Chaetochlorops inquilina* Coq., *Cholomyia longipes* Fab. (Pl. V, C), and *Fannia canicularis* L., were reared from this host in considerable numbers. Two hymenopterous parasites, determined by Mr. R. A. Cushman as *Triaspis curculionis* var. *rufus* (Riley) and *Thersilochus conotracheli* (Riley) (Pl. V, E) were also obtained in the rearing jars. Still another parasite, determined by Mr. R. A. Fouts as a new species of *Belyta*, was found in jars in which this curculio was being reared.

THE HICKORY-NUT CURCULIO.⁸

The hickory-nut curculio is very similar to the two species just discussed, but it attacks the immature nuts of various kinds of hickory instead of walnuts. The beetles appear upon the trees somewhat later in spring than the other two and lay their first eggs in hickory nuts that are at least half grown, although before the nut kernels have begun to form. The most conspicuous manifestation of the presence of the insect is the dropping of the infested nuts about midsummer. It is not unusual in July and August to find in some localities the ground beneath bearing hickory trees strewn thickly with green nuts. Examination of these nuts will disclose a brownish oviposition scar

⁸ *Conotrachelus affinis* Boh.; suborder Rhynchophora, family Curculionidae, tribe Cryptorhynchini.

on the side of the nut (Pl. VI, *C*) and a whitish larva feeding within. (Pl. VI, *D*.) The dropping of nuts from this cause is sometimes very heavy.

HISTORY AND DISTRIBUTION.

This species was described and named in 1837 by Boheman.⁹ Since the original description was published the species has been referred to occasionally by entomologists, but it has at no time attracted extensive notice. It has been recorded from the States of New Jersey, Ohio, Virginia, West Virginia, Louisiana, Florida, and the District of Columbia.

FOOD PLANTS.

During the last 15 years the writer has reared this curculio frequently from hickory nuts in West Virginia. Pierce¹⁰ has reared it from hickory nuts in Louisiana. Apparently its attacks are confined to the nuts of various species of hickory. In West Virginia the nuts of the pignut hickory, *Hicoria glabra*, seem to be preferred to those of other species, although shagbark hickory nuts, *H. ovata*, are sometimes attacked extensively. Nuts of *H. alba* and *H. minima* are attacked to some extent and it is probable that injury may occur to the nuts of all species of hickory that grow within the range of the insect.

LIFE HISTORY.

EGG.

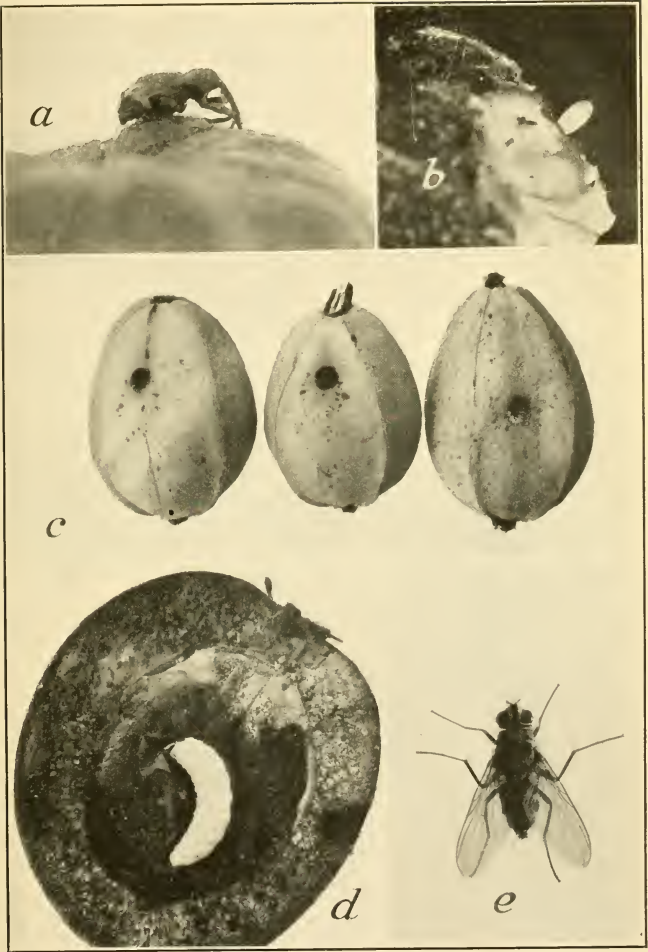
The egg (Pl. VI, *B*) is oblong, elliptical, translucent white, the surface smooth and shiny. The average dimensions are 1 mm. long by 0.6 mm. thick. The eggs hatch in from five to seven days.

LARVA.

The larva (Pl. VI, *D*) is white with light brown head, full-grown specimens measuring 12 mm. in length. The larvæ are practically identical with those of the preceding species except that they taper somewhat more abruptly at the anal end than *Conotrachelus retentus*, and the bristles, with which the body is sparsely clothed, are shorter and less conspicuous than in *C. juglandis*. They are found feeding singly in fallen nuts during the months of July and August. The infested nuts drop about 20 days after oviposition takes place, or about 2 weeks after the larvæ begin to feed. At the time of dropping, the nuts average from one-half to two-thirds grown.

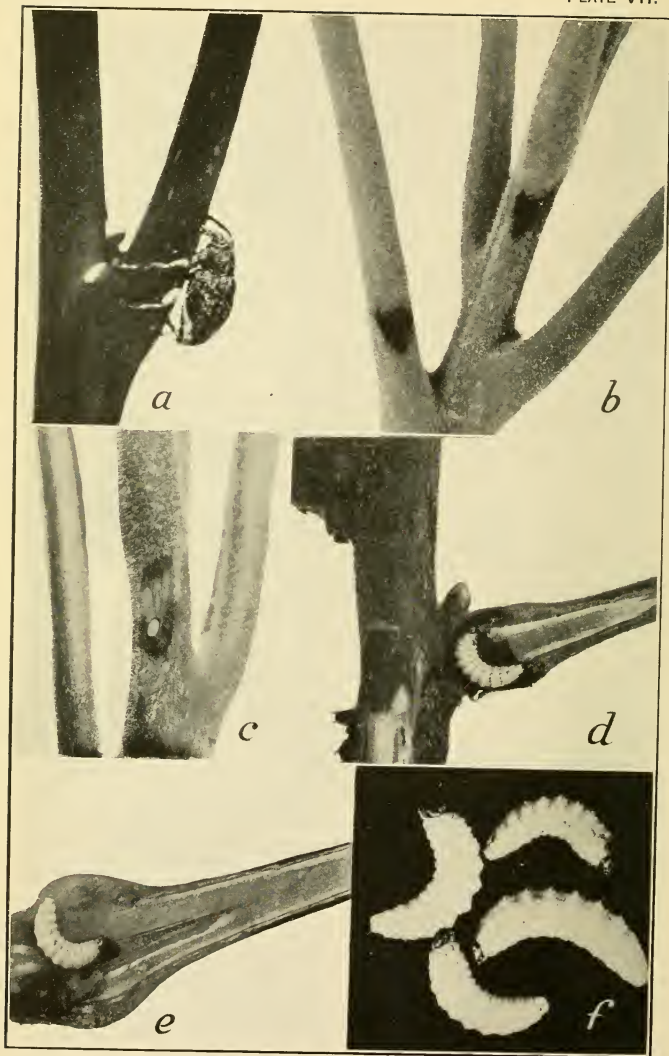
⁹ BOHEMAN, C. H., In SCHOENHEER, C. J. SYNONYMIA INSECTORUM. GENERA ET SPECIES CURCULIONIDUM, t. 4, pars. 1, p. 429-430. 1837.

¹⁰ PIERCE, W. DWIGHT. ON THE BIOLOGIES OF THE RHYNCHOPHORA OF NORTH AMERICA. Studies from the Zoological Laboratory of the University of Nebraska, No. 78. Nebr. State Bd. Agr., Rpt. Zoologist, p. 274. 1907.



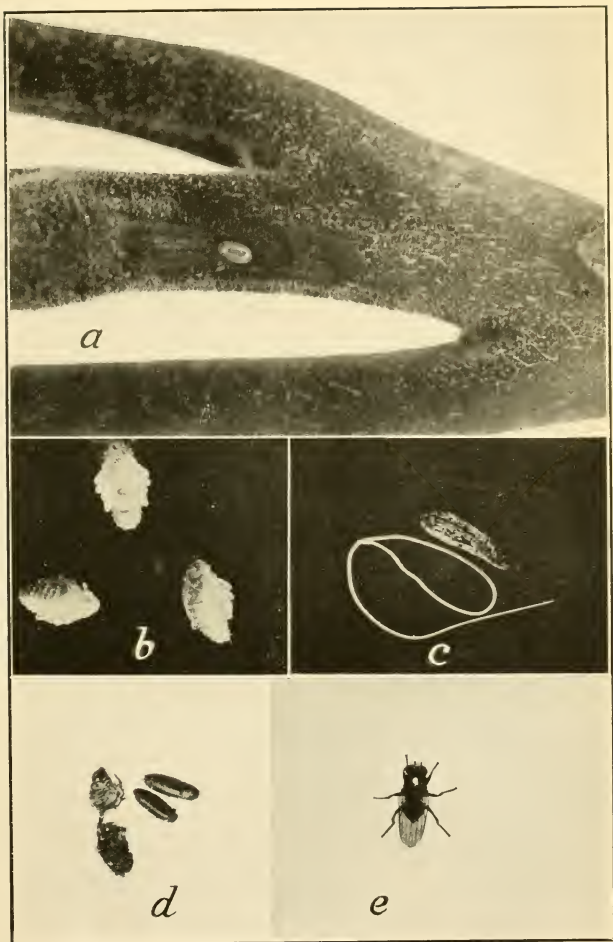
THE HICKORY-NUT CURCULIO.

a, Adult curculio resting on hickory nut; *b*, egg exposed by cutting away the husk of the nut from around the egg chamber; *c*, oviposition scars in shagbark hickory nuts; *d*, larva feeding in shagbark hickory nut; *e*, parasitic fly *Cholomyia longipes*.



THE HICKORY-SHOOT CURCULIO.

a, Adult excavating egg chamber in leaf petiole; *b*, oviposition scars; *c*, egg exposed by cutting away bark; *d* and *e*, larvæ feeding at base of leaf petioles; *f*, larvæ



THE HICKORY-SHOOT CURCULIO.

a, Egg in hickory shoot, exposed by removing bark; *b*, pupæ; *c*, hairworm parasite of larva by dead body of its host; *d*, curculio larva killed by larvæ of parasitic fly, *Chactochlorops inquilina*, with pupæ of parasite on right; *e*, adult parasite *C. inquilina*.

The larvæ continue feeding in the nuts for 10 days or 2 weeks after they are on the ground and then leave through exit holes made at the oviposition scar.

PUPA.

The pupa is delicate white, sparsely covered with short bristles, as in *juglandis* and *retentus*, and is of the same general size and shape as the adult. Pupation usually takes place within unlined cells of earth an inch or two below the surface of the ground. In a few instances pupation was found occurring within host nuts that were buried beneath damp, fallen leaves. The pupa stage covers a period of approximately 30 days.

ADULT.

The adult (Pl. VI, A) is reddish brown with a conspicuous broad band of a lighter grayish shade behind the middle of the elytra. The snout is long, and the general size, shape, and markings of the beetle are similar to those of *C. juglandis* and *C. retentus*. It may be distinguished from *C. retentus* by its more reddish color, the light markings on the thorax and elytra often having a pinkish cast, and from *C. juglandis* by the less prominent humps and ridges of the elytra and also by the more pronounced reddish shade of the elytral and thoracic bands and markings.

The young beetles issue from the ground from August to October; they have appeared in rearing jars at French Creek, W. Va., from August 12 to October 15. Soon after emergence from their pupal quarters they go into hibernation and do not reappear until late the following spring.

Oviposition in the latitude of West Virginia begins late in June and covers a period of at least four weeks. The eggs are laid in circular or sometimes crescent-shaped scars on the side of the nut, the scars soon taking on a brownish or blackish color and becoming rather conspicuous. (Pl. VI, C.) It has been observed frequently that in nuts of *Hicoria glabra* the oviposition marks are made near the point of the nut, while in those of *H. ovata* the marks are directly on the side or near the stem end. Also, beetles developing from nuts of *H. ovata* average larger than those from the nuts of *H. glabra*.

The beetles are especially active at nightfall and have been observed ovipositing after dark.

NATURAL ENEMIES.

Numerous specimens of a parasitic fly were reared in September from larvæ of this curculio. (Pl. VI, E.) The species was determined by Dr. J. M. Aldrich as *Cholomyia longipes* Fab. A few specimens of another fly determined by Aldrich as *Myiophasia globosa* Towns. were also reared from the larvæ. Two hymenopterous species were

found parasitic upon the larvæ; one of these was determined by Mr. R. A. Cushman as *Triaspis curculionis* var. *rufus* (Riley) and the other by Mr. C. F. W. Muesebeck as a new species of *Microgaster*. Pierce¹¹ records rearing the parasitic fly *Myiophasia aenea* Wied. from this host.

THE HICKORY-SHOOT CURCULIO.¹²

Soon after the growth of hickory begins in the spring the tender tips and leaf petioles may be found disfigured by dark, V-shaped marks on the bark about an eighth of an inch long. (Pl. VII, *B*.) These are the egg punctures of a small snout-beetle which may be known as the hickory-shoot curculio. Often these marks occur in series of from 5 to 10 along the shoot, one above each leaf axil. Examination of these marks usually discloses either the single white egg (Pl. VII, *C*; Pl. VIII, *A*) or a small white grub feeding in the stem (Pl. VII, *D* and *E*). The affected tip or leaf usually withers and drops as a result of the injury. No instance of serious loss from this insect has come under the writer's notice, but injurious attacks, especially to newly transplanted hickory trees, are a possibility.

DISTRIBUTION.

This species was described from Kentucky in 1824 and has since been recorded from Massachusetts, Connecticut, New Jersey, Florida, and Texas. The writer has found it abundantly at French Creek, W. Va., and has observed its work in other West Virginia localities.

FOOD PLANTS.

This curculio has been observed attacking the shoots of the following hickories in West Virginia: *Hicoria minima*, *H. ovata*, *H. alba*, *H. glabra*, and *H. pecan*.

LIFE HISTORY.

EGG.

The egg (Pl. VII, *C*; Pl. VIII, *A*) is oval, oblong, creamy white, semitransparent, and averages 1.1 mm. by 0.7 mm. It occupies a shallow cavity at the side of an elongate slit which the female beetle makes with her snout in the bark of tender twigs and leaf petioles. (Pl. VII, *A*.) After the egg is deposited the bark over the egg cavity and along the edges of the slit turns dark and the wound shows as a blackish, triangular spot on the green bark. (Pl. VII, *B*.) Several eggs laid on May 24 hatched on May 30, the incubation period being six days.

¹¹ PIERCE, W. DWIGHT. A LIST OF PARASITES KNOWN TO ATTACK AMERICAN RHYNCHOPHORA. In Jour. Econ. Ent., v. 1, no. 6, p. 390. 1908.

¹² *Conotrachelus aratus* Germ., suborder Rhynchophora, family Curculionidae, tribe Cryptorhynchini.

LARVA.

The larva (Pl. VII, *D*, *E*, and *F*) is yellowish white with brown head and black jaws and is covered with scattering, short bristles, those on the dorsal surface of the last three segments being longer than those elsewhere. The length of the larva averages 10 mm. and the thickness at the middle 2 mm. Except for its slightly smaller size it is practically indistinguishable from those of other species described herein.

The favorite feeding place of the larva is in the heart of the bulb-like swelling at the base of the leaf petiole. (Pl. VII, *D* and *E*.) It also mines in the pith of the shoots and leaf stems, making burrows an inch or two long. The season of activity is in the spring and early summer when the new growth is tender.

PUPA.

The delicate, white pupa (Pl. VIII, *B*) is characteristic of the group and occupies an earthen cell from one-half inch to 2 inches below the surface of the ground. The pupa stage covers a period of not more than two or three weeks.

ADULT.

The beetle (Pl. VII, *A*) is considerably smaller than any other of the curculios discussed herein, an average specimen measuring 5 mm. in length and 2 mm. in thickness. The color is dull grayish brown with a more or less indistinct, broad band of yellowish pubescence behind the middle of the elytra and a narrow line of the same color on each side of the thorax. The snout is stout and curved and as long as the head and thorax combined.

The newly transformed beetles issue from the ground in mid-summer and probably spend thereafter a period of comparative inactivity on hickory trees before hibernating in the autumn. With the bursting of hickory buds the following spring they reappear and begin ovipositing as soon as the shoots are a few inches long. They feed rather freely at this time, eating out small pits which extend through the bark of the young growth. Beetles were found frequently hiding between the folds of the expanding buds of hickory. In ovipositing the female spends 30 to 40 minutes in preparing a place for the egg, and while thus engaged is often guarded closely by a male.

NATURAL ENEMIES.

The larvæ while feeding and developing became rather heavily parasitized, at least 50 per cent of them dying from this cause during the two seasons they were kept under observation. Three species of

flies, determined by Dr. J. M. Aldrich as *Myiophasia globosa* Towns., *Cholomyia longipes* Fab., and *Chaetochlorops inquilina* Coq. (Pl. VIII, *D* and *E*), were reared from the larvæ. Two larvæ in rearing cages died when full-grown and from each of their bodies there issued a hairworm several inches long, the species of which was not determined (Pl. VIII, *C*).

METHODS OF CONTROLLING NUT-INFESTING CURCULIOS.

The dropping of curculio-infested walnuts and hickory nuts before the larvæ within them mature affords an opportunity for destroying the young insects by collecting and burning, or otherwise disposing of the fallen nuts. This method can be resorted to with success, however, only in cases of isolated trees or plantations. In localities where the nut trees abound in woods a sufficient number of the curculio beetles will develop on them to visit and injure any near-by plantations of the same kind. Where this means of reducing the insects is practiced collections should be made as often as once a week in order to secure the nuts before the larvæ leave them to enter the ground for the completion of their development.

All the curculios discussed herein do more or less feeding in the beetle stage before oviposition begins in the spring. A considerable part of this food consists of the surface tissues of stems, leaves, and fruit. This makes it possible theoretically to destroy the beetles before their eggs are laid by spraying with arsenical poisons. Limited experiments by the writer indicate that lead arsenate applications soon after growth starts in the spring can be counted on to give good results in reducing injury, at least from the butternut and black walnut curculios.

Britton and Kirk¹³ have found that spraying walnut trees with lead arsenate at a strength of 6 pounds to 50 gallons of water is an effective method of controlling the butternut curculio. Morris,¹⁴ in writing of attacks of the butternut curculio which were so extensive as to kill nearly 300 young English walnuts and several hundred young Japanese walnuts, states that subsequent spraying with 1 pound of lead arsenate to 10 gallons of water killed the beetles and prevented further injury.

¹³ BRITTON, W. E., and KIRK, H. B. Op cit.

¹⁴ MORRIS, ROBERT T. METHOD FOR COMBATING THE WALNUT WEEVIL. In Amer. Nut Journ., v. 10, no. 5, p. 71. 1919.

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BIOLOGY OF THE LOTUS BORER (*PYRAUSTA
PENITALIS* Grote).

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INTRODUCTORY.

In American literature two distinct species have been confused under the name *Pyrausta penitalis* Grote. One of them, the smartweed borer, has recently been described as new under the name *P. ainsliei* by Carl Heinrich (16¹), of the Bureau of Entomology. The other, the lotus borer, described originally by Grote (1) and later redescribed by Smith (3) as *Botis nelumbialis*, has been casually studied by several observers, but up to the present time no complete account of its biology has been available. The two species are closely related and very similar, in many morphological and biological characters, to the recently introduced European corn borer, *P. nubilalis* Hübner. It seemed possible that a close study of the life history and habits of the two native species might bring to light some facts which would help in determining the potentialities of the new pest. In accordance with this plan the first paper dealing with *P. ainsliei* from the biological side has already been published (18). The present paper deals with the similar aspects of *P. penitalis*. Both the results

¹ Reference is made by number (italic) to "Literature cited," p. 13.

of the writers' observations and previously published data are included herein. The morphology and diagnostic characters of this and the other species mentioned, which have already been admirably worked out by Heinrich (16) and also by Flint and Malloch (17) and Mosher (13, 15), are largely omitted from this discussion.

SYSTEMATIC HISTORY.

Pyrausta penitalis was first described by Grote (1) under the generic name *Botis* from material taken on *Nelumbo lutea* at Lawrence, Kans. In 1890 it was redescribed by Smith (3) as *Botis nelumbialis* from "Egyptian" (more properly "Indian") lotus, *N. nucifera*, at Bordentown, N. J. Thinking that he was dealing with this species, Coquillett (2) published some notes on a form which has since been shown (12, 14) to be distinct, probably *P. fulitalis*. Riley and Howard (4, p. 349, Townsend (5, p. 467), Coquillett (7, pp. 15, 17, 19, 27), and Viereck (11, p. 453) record parasites which will be more fully noted later. Hart (6, p. 180), gives some scattered biological information and descriptions of the various stages as observed on *N. lutea* along the Illinois River. Coquillett (7) first used the name in its present form, and Dyar (9, p. 391) lists the species as occurring in the south Atlantic States, with *B. nelumbialis* Smith as a synonym. Chittenden (12) summarized all the facts available up to the time of his paper and from them formulated a tentative life cycle which, because of the fact that he was considering two species, one of them at the time undescribed, will have to be considerably modified. Welch (14) has made the latest contribution to our knowledge of the species, and his observations, made at Sandusky Bay, Lake Erie, although good, are incomplete as to life history, because they covered only a small part of the growing season. His conclusions, however, come nearer the facts than any hitherto published.

STUDIES AT KNOXVILLE, TENN.

FIELD COLLECTIONS.

The authors' work on the species dates from July 19, 1919, when, after considerable search, a plantation of the yellow lotus or water chinquapin (*Nelumbo lutea*) (Pl. I) was located at Kimberlin Heights, about 15 miles from our laboratory at Knoxville, Tenn. This plantation consisted of a dense border of the plants surrounding a mud-bottomed pond of about 3 acres on the campus of a small denominational school. It was said that the plants had started several years before from seeds thrown into the pond by one of the students. As nearly as the authors have been able to ascertain, this is now the only occurrence of the plant in eastern Tennessee, although it is known

that before the coming of the white man the Indians cultivated it for its edible seeds and rootstocks in many places along the Cumberland and Tennessee Rivers.

The first examination showed that the plants were heavily infested by the very insect the writers desired to study. Throughout the rest of the season of 1919 frequent careful studies were made of the conditions at Kimberlin Heights, and quantities of material were brought to the laboratory for closer study and for rearing purposes.

At the time of the first visit, July 19, the main blooming season was closing. There were still a few flowers and scattering buds. None of the seed pods had ripened, but the oldest ones were fully grown. A count showed that there were 472 pods in all stages in the plantation. Of these, 80 (17 per cent) showed work of the larvæ and were collected and examined individually. They contained 39 empty pupal shells, 23 pupæ, and 2 larvæ in the prepupal stage. Moths began to emerge at once, or, more properly, continued to emerge from the pupæ until July 28, when the last one appeared.

On July 19, larvæ, evidently the progeny of the earliest moths, were found feeding on the leaves. These larvæ were mostly small, only a few half grown, and none mature. When taken to the laboratory for rearing they began to pupate July 28, and the first moths of this generation emerged August 4. From this time on there was a continual overlapping of generations, larvæ both from the later moths of the first generation and from those of the second being inseparably mixed. From these larvæ and from others collected on July 28, moths continued to emerge until August 27. On August 5 no very small larvæ could be found. The youngest observed probably were in the third instar, but several egg masses were found, so it seemed probable that the last moths of the first generation had not yet disappeared. On this same date it was also found that the larvæ of this generation instead of seeking pupation quarters in the seed heads were burrowing in the upper ends of the petioles of the older leaves, preparing there a pupation chamber, and that a few had already pupated. One empty pupa shell was found in this location, which seemingly indicated that the second generation of moths had just begun to emerge. More pupæ and prepupal larvæ subsequently were found in the petioles, and larvæ, in gradually lessening numbers, still feeding on the leaves and in the petioles, were found until September 18. Three were found on this date, but thereafter the most thorough search of the lotus and of all likely hiding places in the vicinity of the pond failed to reveal a trace of their whereabouts.

A further and more careful study in this locality was planned for 1920, but for some obscure reason the lotus was very much less vigorous. Comparatively few leaves and buds appeared and only a few small larvæ were found in colonies on June 29.

REARING RECORDS.

So much for field observations. On each examination of the pond material was collected and brought to the laboratory for rearing. The results obtained throw additional light on the seasonal habits of the moths. As stated above, pupæ taken in the seed heads July 19 continued to develop moths until July 28. Larvæ taken at the same time on the leaves varied greatly in size, some of them being very small. The first of these pupated July 28, the last August 15. Moths emerged from August 4 to August 22. Another collection of larvæ made from the leaves July 28 pupated August 3 to August 18, and moths emerged August 12 to August 27. A mass of eggs found August 6 hatched August 9, and the larvæ were reared. They pupated August 28 to September 2, and the moths emerged September 9 to September 17. Another series of larvæ taken both from petioles and leaf blades on August 5 pupated from August 6 to August 22, and moths emerged August 13 to August 29. Larvæ from a lot of 67 collected August 15 pupated from August 17 to September 12, and moths emerged August 28 to September 22.

LIFE CYCLE.

Assuming for the present, as seems probable, that the species passes the winter in the larval stage, it is evident that the life history must be substantially as follows:

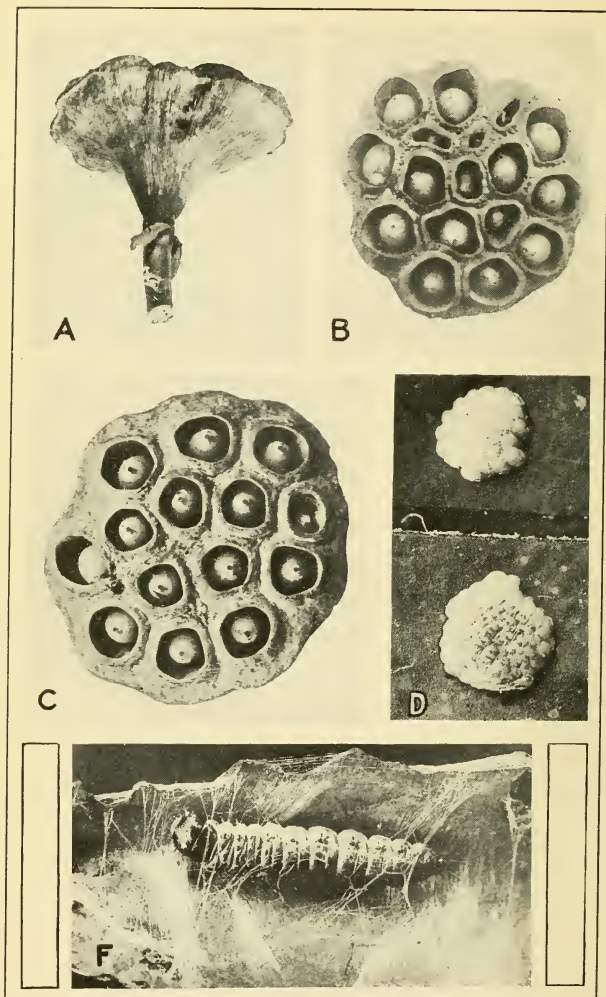
The overwintering larvæ pupate and the moths emerge and oviposit about mid-June. The resulting larvæ feed on the leaves, and when fairly grown, about July 1, seek the flowers and enter the young pods, feeding upon them to some extent and pupating within them. The moths of this first generation emerge from July 7 to July 28. Eggs are at once produced by these moths and constitute the first stage of the second generation. The eggs soon hatch, and the oldest of the larvæ produced are approximately half grown by July 19; but moths of the first generation continue to oviposit until about August 5, so that second-generation larvæ are hatching continuously from July 10 to August 8. A collection of these larvæ made July 28 pupated August 3 to 18 and moths emerged August 12 to 27. These larvæ of the second generation feed on the leaves and pupate in the upper ends of the leaf petioles.

The moths of the second generation give rise to the third-generation eggs and larvæ, which survive the winter and constitute the spring generation. It seems possible that some of the smaller larvæ of the second generation seek hibernation quarters instead of completing their growth the same fall. In this case there would be only two generations annually, but it seems probable that there are three generations as a rule. Their behavior from the time the larvæ seek



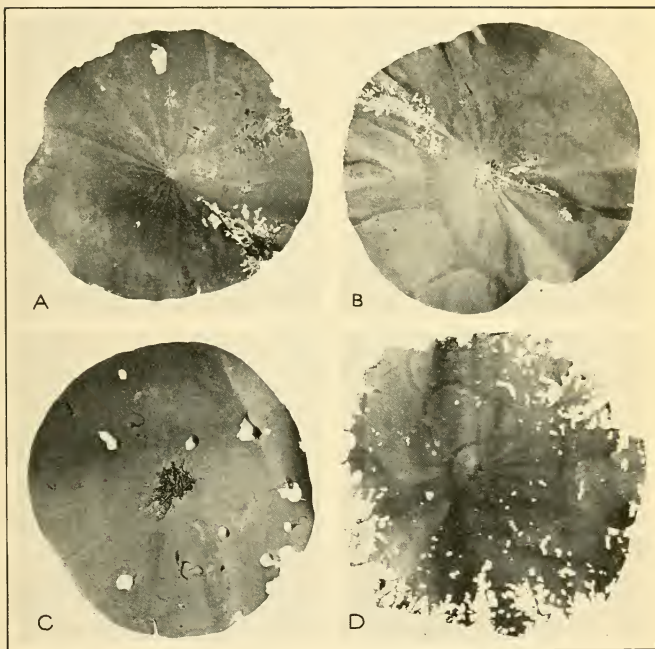
PYRAUSTA PENITALIS.

A, Partial view of pond at Kimberlin Heights, Tenn., showing *Nelumbo lutea* flowers, ripe pods, and margin of old dying leaves floating on water. B, Method of pod development in lotus: a, Bud; b, growing pods in horizontal position; c, erect, mature pods; d, pod deformed by work of borer.



PYRAUSTA PENITALIS.

A, Under side of infested pod, showing entrance hole of borer. *B*, Same pod as in *A*. Face view showing deformed sockets and seeds caused by work of larva beneath. *C*, Face of another pod, showing less common method of entrance. *D*, Egg masses on leaf surface. *F*, Larva beneath web on leaf.



PYRAUSTA PENITALIS.

A, Injured leaf. *B*, Leaf bearing both central and peripheral feeding areas. *C*, An old floating leaf, showing mound of frass covering the opening to the pupal chamber in the petiole beneath. *D*, An old, much eaten leaf after the remaining membrane has dried and dropped out.



PYRAUSTA PENITALIS.

A, Portion of plantation at Kimberlin Heights, Tenn., showing close association of lotus and cat-tail rush. *B*, Upper end of leaf petiole, opened to show pupal cavity and cocoon. *C*, Same as in *B*. Leaf cut in half and petiole split to show position of pupal cavity.

winter quarters in the fall until the young larvæ of the first generation appear on the leaves in June is unknown, and the outline here given for that period is hypothetical.

FEEDING HABITS ON THE LEAVES

After hatching, the larvæ feed gregariously for a time, gnawing off the epidermis of the leaf in irregular patches, first protecting themselves with a shielding network of brownish silk stretched across some slight concavity of the leaf or producing such a concavity by its tension. They soon scatter, each forming a similar retreat of its own (Pl. II, F), either in the center of the leaf above the petiole attachment or around the margin where the edge is easily drawn up a little to form the necessary free space beneath the web (Pl. III, A, B). Less often a larva locates on the blade between the center and the margin. Protected and partially screened by the webs, the larvæ strip the epidermis from the leaf, those at the center in a more or less radiate pattern and those at the margin following the periphery. They extend their retreat as they exhaust the food supply and occasionally prolong the feeding area irregularly inward toward the disk of the leaf. At no stage is the entire substance of the leaf eaten. The areas from which the epidermis is stripped soon turn brown, dry, and fall out, leaving the leaf lacelike along the margin (Pl. III, D) and generally tattered in appearance.

Although at Kimberlin Heights no larvæ were observed in the act, it is evident that they moved about from leaf to leaf and from one portion of a leaf to another. Small feeding webs were often found uninhabited, and tiny larvæ were found in retreats evidently occupied previously by much larger ones. Where several larvæ occurred on one leaf the retreats often overlapped around the margin, giving the effect of a large retreat occupied by several larvæ. No evidence was found of the larvæ swimming from one leaf to another as was observed by Welch in Lake Erie. The leaves were in almost every case contiguous to each other, especially when swayed by the breeze, and no need for such a means of locomotion was apparent. Then, too, the old floating leaves, loose from their petioles, drifted back and forth across the pond before the wind and, working in among the standing leaves, formed pontoon bridges between the petioles. (Pl. I, A.)

One exceptional instance was observed in which a leaf standing somewhat by itself but not especially isolated was found with a series of six holes in the petiole between the blade and water, each of which opened into a short cavity containing a fully mature larva evidently preparing to pupate. Not another larva was found in such a location, and this case can only be explained on the ground

that the larvæ marooned on this leaf, unable to seek their usual pupation quarters, were forced to enter the petiole.

From laboratory experiments it was found that when placed in water the larvæ, especially those nearly mature, were sustained on the surface film and were able to make considerable progress by lateral contortions. When once fully submerged, however, they were unable to regain the surface. Larvæ of *Pyrausta ainsliei* under the same conditions behaved similarly but did not advance as rapidly when swimming.

FEEDING HABITS ON THE PODS.

The larvæ of the first generation apparently utilize the green, growing pod for food as well as for pupation. After the floral parts fall away, the pod normally droops (Pl. I, B, *b*) until its flat, seed-bearing face is vertical, becoming erect again when nearly mature (Pl. I, B, *c*). Until maturity the seeds remain tightly embedded in their sockets, and only as the pods ripen, turn brown, and dry do they become loose, ultimately to be shaken out and sink in the water and mud around the plants.

In entering the young pod the larva usually selects a point just below the rim and on the underside of the pod as it hangs horizontally (Pl. II, A); less often it cuts in between the seeds on the flat face of the pod (Pl. II, C). As the larva feeds within, soft brown frass is pushed out of the entrance hole in considerable quantity, eventually drying and falling away or being washed off by rain. The interior of the fruit or pod is filled with parenchymatous tissue through which run the vascular bundles nourishing the developing seeds. After entering, the larva eats out more or less of a cavity in this soft tissue and often cuts into or through two or three or more of the seeds. Whenever a seed is injured even slightly or the vascular bundle beneath it is cut, it turns brown and soon shrivels to a mere remnant. These empty or partially empty sockets (Pl. II, B) are very conspicuous and almost invariably indicate the presence or work of the larvæ. Such injured pods are also frequently much distorted (Pl. I, B, *d*) and very unlike the ornamental, perfect specimens. Although in a few cases the cocoon was found near the face of the pod and, in fact, lying partially in and through some of the injured seeds, the larva usually makes its way well toward the base of the pod before cocooning.

In the pods collected at Kimberlin Heights July 19 the normal number of seeds per pod varied from 10 to 25, with an average of 17. The work of the larvæ resulted in the destruction of 5.9 seeds on the average in each infested pod, or 34.7 per cent of the total number in the infested pods and 5.88 per cent of those in the entire plantation. The pods developing from the scattering flowers which

continue to appear after the main blooming season are generally smaller, contain relatively few seeds, and often have empty sockets due to incomplete fertilization.

So far as is known, this lotus has at present no economic value other than its very obvious qualifications as an ornamental plant. The work of the larvæ of this insect on the leaves (Pl. III) is conspicuous and unsightly, and the attacks on the pods result in many misshapen and distorted specimens as well as in the outright destruction of an appreciable proportion of the seeds.

PUPATION OF THE FIRST GENERATION.

Pupæ of the first generation are formed in dense, tough, papery cocoons in the growing pods. The cocoon is not conspicuous even when the pod is opened, as it is stained and studded with brownish excrement like the walls of the burrow. In the great majority of cases it lies well toward the base of the pod with its long axis parallel with the vascular bundles running to the seed sockets. Less often it is found lying partially within or through one or more of the partly consumed seeds. The cocoon and pupa are so much larger than the seeds that it seems impossible for the pest ever to be accidentally distributed in them. Larvæ have been found lying entirely within a single immature seed but never a pupa. In the cocoon the pupa lies with its head toward the entrance, and after emergence occurs the pupal shell remains entirely within the cocoon. The moth escapes from the pod by the same opening through which the larva entered it.

PUPATION OF THE SECOND GENERATION.

In the second generation the pupal habits are quite different, and considerable search was required to locate the cocoon and pupa. Even though a few pods continued to develop from stray flowers, they were found attacked by larvæ in only one or two cases, and the increasing number of larvæ reaching maturity made it certain that they were seeking other quarters. Two possibilities were open—the over-curved margins of the leaves and the petioles. The leaf margins yielded only a very occasional pupa, not enough to solve the problem, and the petioles, standing as they did from 15 to 30 inches above the water and offering apparently ideal conditions for a pupal burrow, remained unscarred. To be sure, an occasional shallow pit was found in the upper end, opening to the upper surface of the leaf blade, but never one large enough to contain a larva.

The lotus at least in this plantation holds the leaves high above the water on their stiff and milky-juiced supporting petioles until, either from maturity or because of serious injury to the leaf surface, they have about reached their limit of usefulness. The petioles then

weaken and allow the leaf disks to drop to the surface of the water (Pl. I, A), where they soon yellow, decay, and sink. When these mature floating leaves were examined it was found that in the center of the disk, directly above the petiole attachment, a large number of the leaves had a round opening leading to a cavity in the upper end of the petiole (Pl. IV, B, C). This cavity was shallow, seldom extending more than 2 centimeters into the petiole, and usually just long enough to accommodate the larva and its cocoon. The entrance was often surrounded and covered by a mound of soft brown frass pellets (Pl. III, C), and frequently the surface tissue of the leaf in an irregular area about it was scarred and eaten as if the larva after constructing the cavity possessed still an appetite which it satisfied with the nearest food at hand.

In the case of the prepupal larvæ or pupæ the cavity in the petiole is lined with a substantial white silk fabric, densest at the upper end (Pl. IV, B). The entrance is closed with a very accurately cut whitish lenticular disk of plant tissue which fits closely and is sealed in with silk. This disk lies usually a little below the level of the leaf surface and is concealed by the frass until the latter is washed away or otherwise removed. This position of the pupal cavity, in the floating leaves only, brings it below the water level.

Welch (14, p. 219-221) has well described the construction of this pupal chamber and the feeding in connection therewith, and the behavior of the insects was found here to correspond closely with his account. It is noteworthy, however, that in Lake Erie, where his observations were made, the lotus leaves are always floating and not held above the water, and their centers are higher than the periphery, while at Kimberlin Heights the leaves are held 15 to 30 inches above the water and are cupped with the margins higher than the centers, so that they often catch rain or dew to the amount of several cubic centimeters and hold it until it evaporates or is spilled by the swaying of the leaves in the wind. The insect evidently prefers to construct its cocoon in an aquatic situation and so seeks the old floating leaves at the approach of maturity. Never were young or partly grown larvæ found in the petioles, only those nearly mature and probably in the last instar. Neither are the young and erect leaves attacked in this way; only the old, floating ones.

HABITS OF THE MOTHS.

The only moths seen in the open were the few found in and near the lotus plantation. Several of them were captured and found to be predominantly males. Their flight was rapid and erratic, and they were wary and not easily approached. They came to rest usually on the lower side of a lotus leaf and often flew among the petioles and beneath the canopy formed by the leaves 2 or 3 feet

above the water. No data are available as to the length of life of the moths in the open. A series of reared moths retained alive in tin boxes supplied with a wad of wet cotton furnished the data on this point contained in Table I.

TABLE I.—*Length of life of reared moths in confinement (in terms of days).*

Sex.	Maximum.	Minimum.	Average.	Number of moths averaged.
Male.....	14	2	6.77	27
Female.....	13	3	7.72	43

THE EGG.

The act of oviposition has not been observed, but very probably occurs toward dusk or at night. Nothing was known about the egg until Welch (14, p. 214) observed and rather incompletely described it. The authors have found numbers of the masses (Pl. II, D) at various times, and as their observations differ in some points from those of Welch a description in somewhat greater detail is included.

The egg: Thin, flat, elliptical in outline, 0.98 millimeter long, 0.56 millimeter wide, chorion finely reticulated with narrow elevated lines and in addition finely longitudinally wrinkled, dingy yellow or amber color when laid, soon developing a narrow darker border and a paler opaque central area. They are laid in thick circular masses of 40 to 80 eggs, 2.5 to 3 millimeters in diameter and 0.47 millimeter thick, each egg overlapping its predecessor shingle-fashion, about three-fourths covering it and lying at an angle of approximately 45° with the leaf surface, the mass being dingy yellow in general color. The larva leaves the egg through a transverse slit in the exposed end. After hatching the mass is dirty gray in color, somewhat shining, and much flatter than before. It is then very loosely attached to the leaf and easily removed by a slight touch.

The writers failed to note any matrix such as Welch describes. They did, however, note the frequent absence of the empty egg mass on leaves bearing very small larvæ, but attributed the fact to the ease with which the empty egg mass is washed or blown from the leaf. A number of the egg masses were found, both unhatched and empty, and one in which the eggs were parasitized. They seem to be placed at any point on the upper surface of the leaf and when present on an unblemished leaf are easily seen.

It has, of course, been impossible to determine how many eggs are normally laid by a female in the open. The possibilities are indicated, however, by results obtained from reared moths confined in tin boxes and supplied with moisture. Of 43 females so confined only 15 oviposited. The number of eggs produced by an individual varied from 9 to 504, with an average for the 15 of 143 eggs. These moths

were all isolated before emergence and remained virgins throughout their lives, so these figures are doubtless below the normal.

FOOD PLANTS.

Unless some food plant other than lotus is inhabited by this insect, it is difficult to explain its presence at Kimberlin Heights. From present knowledge of its habits it is inconceivable that it came with the seeds, and no other lotus is known to exist within possible range of flight of this moth. To determine whether the species is indigenous or introduced, the writers have made plantings of lotus seed in several isolated ponds many miles distant from this infestation.

Because of the confusion in the literature between this species and *Pyrausta ainsliei*, several food plants have been attributed to it which manifestly are erroneous. The only natural food plants which have so far been reliably ascertained are the yellow lotus, *Nelumbo lutea*, and the Indian lotus, *N. nucifera*, the latter an introduced species.

Smith (10, p. 525), mentions having found these larvæ in stems of cat-tail flag, *Typha latifolia*. At Kimberlin Heights conditions were ideal for such a transfer, because the lotus and cat-tail grew intermingled in several places (Pl. IV, A). In attempts to find where the larvæ went for the winter, practically every cat-tail plant in the vicinity of the pond was thoroughly dissected and examined. With the single exception of one larva found behind a leaf sheaf no trace of attacks on this plant were found.

In confinement in the laboratory partly grown larvæ, taken on lotus, fed readily and completed their growth on leaves of smartweed (*Polygonum pennsylvanicum*), buckwheat (*Fagopyrum fagopyrum*), and dock (*Rumex crispus*). In other series, larvæ were reared from egg to adult on the same plants but the authors have never seen any indication that these plants are used as food by this insect under natural conditions. Numerous aquatic and subaquatic plants and a large number of the common wild plants and weeds were offered to the larvæ, but all were refused except those mentioned. It is noteworthy that the normal food plants of *P. ainsliei* are Polygonaceæ but that that species can not develop on lotus. There is a suggestion here of some common ancestry for the two species, with members of the Polygonaceæ as their food plants, and that *P. penitalis*, having taken to lotus comparatively recently, has not entirely lost its taste for the smartweed family.

ENEMIES.

In the course of its life several perils threaten the safety of this insect. It does not seem to us that Welch's point (14, p. 218), as to the construction of the silken web being a special adaptation to its

aquatic environment, is well taken, for many leaf and tree-feeding caterpillars, exposed to the same or to greater risks, do not construct protective webs and, on the other hand, many larvæ living in sheltered and well-protected situations do build burrows or webs—within which to work. Be that as it may, there is probably little danger of wind or waves washing these caterpillars off the leaves.

DIPTEROUS PARASITES.

From living enemies, however, they do not escape so easily. According to the literature four species of tachinid flies have been reared from the larvæ. Townsend (5) lists *Exorista hirsuta*, O. S. (now *E. vulgaris* Fall.) and *Phorocera comstockii* Will. as having been reared by Forbes in Illinois. Coquillett (7, p. 17, 19) adds *Hypostena variabilis* Coq. and *Panzeria penitalis* Coq. to this list. Because of the confusion between *Pyrausta penitalis* and *Pyrausta ainsliei* and the impossibility of finding from the literature the exact source of the material from which the parasites were reared, it is possible that not all of these species attack the true *Pyrausta penitalis*. *Panzeria penitalis*, for one, is known to be a parasite of *Pyrausta ainsliei*, and there is no definite record of its ever having been reared from lotus-feeding larvæ. All of these records should be verified in the light of our more exact knowledge of their hosts.

HYMENOPTEROUS PARASITES.

Among the hymenopterous parasites, *Bracon xanthostigma* Cress. is listed by Riley and Howard (4, p. 439) as a parasite of this borer on lotus at St. Louis, Mo. Viereck (11, p. 223) lists *Meteorus communis* Cress. with the simple statement that it parasitized *P. penitalis*. Hart (6, p. 180) mentions one secondary and two primary parasites, but without determinations. We recognize at least one of his parasites, the braconid, making white cocoons singly on the leaf surface. (Pl. III A.) This one, determined as *Apanteles harti* Vier. by A. B. Gahan, was found to be the most common at Kimberlin Heights. Its small white cocoons (1.5 by 4 millimeters) are firmly fastened to the leaf disk either under the webbing or exposed outside. In July they were only occasionally seen, but by early September were much more common and were killing from 10 to 25 per cent of the larvæ. This species evidently attacks the smaller larvæ and completes its life as a parasite when its host is scarcely more than half grown. None of them developed from larvæ larger than this. From 7 to 10 days elapsed between the spinning of the cocoon by the parasite and the emergence of the adult.

Another parasite, very likely the other mentioned by Hart (6, p. 181), which the writers found only a little less common than the foregoing, is an undescribed, yellowish brown species of *Microbracon* (de-

terminated by Gahan). The parasitic grubs to the number of about a dozen emerge from their host larva shortly before time for the pupation of the latter. They then spin a mass of brown silk cocoons so tightly compacted that it is difficult even to determine their number. This mass is found in the burrow or partially constructed cocoon of the host. In more than one instance adults of this parasite were found well within the larval burrow of the host, evidently hunting opportunities for oviposition, but it is not known just how or at what age the host larvæ are attacked.

In three instances *Chalcis ovata* Say (det. Rohwer) was reared from the pupæ by the authors.

The authors found but one case of egg parasitism. One egg mass was taken which appeared darker than normal. When retained in a vial, part of the eggs hatched normally, but the rest, which had meanwhile turned jet black, gave forth adults of *Trichogramma minutum* Riley (det. Gahan), one from each egg.

SCAVENGERS.

Very often small dipterous maggots were found in the empty burrows or feeding on decaying larvæ or pupæ. A number were reared, and two species of flies were obtained, *Aphiochaeta chaetoneura* Malloch (det. Greene), and *Elachiptera nigriceps* Loew (det. Aldrich). These were undoubtedly scavengers, and nothing was observed to indicate that they were in any way injurious to sound larvæ or pupæ. They seem to thrive equally well on putrid vegetable matter. Coquillett (8) mentions rearing the latter of the two species from the same situation many years earlier.

OTHER ENEMIES.

A somewhat peculiar catastrophe was found to happen very often to the larvæ which had prepared their pupation chambers in the upper end of the petioles of the floating leaves. Some animal, evidently, took a bite out of the side of the petiole close under the leaf, thereby cutting into the cavity and its occupant. In some such cases the cut-out portion of the petiole was left hanging, in others it was gone, and often the predator had bitten the petiole entirely off at this point. No portion of the larvæ or pupæ was ever found in the cavity, and the work was very evidently done intentionally in search for the insect. Often uninfested petioles were cut, evidently by mistake. The possible authors of the work were (1) ducks, a small flock of which frequented the pond; (2) frogs, of which there were many, some of them very large; (3) fishes; and (4) turtles. The character of the work eliminates the ducks and frogs because their jaws are not sufficiently strong to make such clean cuts as these were. No direct evidence of the presence of fish was found, and in such

a pond it would not be usual to find fish capable of doing such work. There remain the turtles, whose heads were frequently seen above the water. The authors were unable to capture any to examine their stomach contents, but by elimination they appear to be the most probable authors of the mischief. Doctor Welch writes that he observed nothing of the kind in Lake Erie. The effect of the work of this depredator was a substantial reduction in the number of larvae reaching maturity.

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EXPERIMENTS WITH SPRAY SOLUTIONS FOR
PREVENTING INSECT INJURY TO GREEN LOGS.By F. C. CRAIGHEAD.¹*Specialist in Forest Entomology, Forest Insect Investigations, Bureau of
Entomology.*

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USES FOR REPELLENT SPRAYS AGAINST FOREST AND SHADE-TREE INSECTS.

During the past few years there has been an increasing demand for a practical spray that will prevent insect attack to crude forest products such as green saw logs and timbers used in rustic construction. Numerous requests for such a spray are received by the Bureau of Entomology. These inquiries often number more than a hundred through the summer months.

Although many lumbering firms request a spray for this purpose, it is doubtful whether it would be really practical under ordinary conditions. During the flight period of those insects which cause the injury it would be necessary to apply the spray immediately after felling the trees. It is more practical to prevent insect injury in lumbering operations by some alteration in the methods of management, as by more prompt handling between felling and sawing or by submerging the logs in water, than by spraying.

¹ Resigned December 31, 1920.

Frequently, however, storms blow over many millions of feet of saw timber. Cases are on record where a single firm has lost in such a manner 100,000,000 board feet. It is a physical impossibility to log these trees promptly and get them to the saw or into a place of safety, although from 40 to 60 days' delay may mean total destruction of the sapwood by borers. It might be feasible, however, to saw these trees into log lengths and spray with some solution that would prevent insect attack for two or three months, or until it was possible to haul them to the mill.

The increasing use of the national forests and parks for recreational purposes has resulted in the construction of many rustic cabins. Insects attacking the timbers in these buildings cause annoying exudations of boring dust and loosen the bark so that later it peels off, thus marring the artistic effect. Much of this injury to rustic work could be prevented by cutting the trees at certain periods and by proper seasoning. Frequenters of summer camping grounds can not always plan to cut the trees at the proper time; in fact, it is more frequently the case that the building is constructed during the summer months and the timber felled at that time—a period when the wood is most susceptible to insect attack.

Thus in both situations it is often the case that the more practical and economical means can not be used.

There is also a considerable demand for a suitable repellent spray against certain shade-tree insects. Wood borers attack various species of living trees, causing considerable injury or death. Under certain circumstances a spray could be used advantageously to repel such insects and prevent oviposition. It would necessarily have to be of materials that would not burn the younger bark, although, except for mechanical difficulties, it would only be necessary to apply the spray to the main trunk and larger limbs, since these are the only parts attacked. Spray materials, the cost of which would be prohibitive for the protection of forest products, might be employed on shade trees.

Under circumstances such as the foregoing it is evident that a practical spray for the prevention of insect injury would be of much benefit and its use should result in a considerable saving of forest products and shade trees.

Owing to the many different insects, their different methods of attacking the logs, the many kinds of wood to be protected, and the exposure to weather conditions, the practical solution of this problem presents many difficulties. Several solutions have been found to meet the requirements, except that they are too expensive or too difficult to apply. In the hope that the results so far obtained may be a stimulus for further suggestions or work along this line the

problem and the preliminary experiments conducted during the years 1916 to 1919 are here presented.

REQUISITES OF A PRACTICAL SPRAY.

It may be impossible to find a single spray solution that can be used with success under all conditions, but it may be possible to obtain good results by using several solutions, each of which is effective under certain conditions. Any spray to fulfill all the requisites necessary for practical effectiveness must possess the following qualities:

IT MUST BE EFFECTIVE AGAINST SEVERAL TYPES OF INSECTS.

Many species of insects attack green timber. Some attack only certain kinds of wood while others show little discrimination. In some cases the injury is caused by the grubs or larvæ feeding beneath the bark or in the wood, or by an adult which bores through the bark and produces larvæ that feed under the bark. According to their method of attacking the wood, boring insects may be divided into the following four groups:

Type 1. Those that lay eggs in crevices of the bark. The larvæ hatching from these eggs then bore through the bark and later into the wood.

Type 2. Those that gnaw a hole through the bark and insert the egg beneath. The larvæ start feeding directly beneath the bark and later bore into the wood.

Type 3. Those that bore through the bark and wood as beetles, to make a suitable place for developing a new brood. The grubs in this case never cause injury.

Type 4. Those that bore through the bark as beetles and lay the eggs beneath the bark. The resulting larvæ feed beneath the bark and loosen it.

The only spray that could possibly be effective against all these types would be one of a disagreeable odor acting as a repellent, thus driving away the adult beetles and preventing oviposition. Poison sprays that will penetrate the outer layers of bark will kill the young larvæ of type 1, but experiments have demonstrated that such materials are not effective against types 2, 3, and 4. In these types most of the beetles do not eat any of the bark or wood as they chew through it and consequently are not poisoned. Possibly a poison combined with a sticky substance that would form a film over the bark and adhere to the mouth parts of the insects might kill them.

Insects of type 4 are not very injurious to saw logs, as they only work beneath the bark and do not enter the wood, but they are important in loosening the bark from rustic work. The others are all injurious to both classes of timber.

IT MUST BE EFFECTIVE ON VARIOUS SPECIES OF WOOD.

The type of bark makes considerable difference in the application of a spray. A bark which is very absorbent, such as that of ash or juniper, readily takes a spray; on the other hand, a smooth bark, such as beech or hickory, will absorb scarcely any of it. Such smooth bark does not hold the spray well but allows it to be easily washed off in the rain. In the latter case poison sprays would hardly be effective. The irregularities of the bark and all crevices must be thoroughly covered.

IT MUST NOT BE LEACHED OFF BY RAIN OR OTHER WEATHER CONDITIONS.

One of the greatest difficulties in the experiments to find an effective spray has been that the solutions are soon washed off by rain. Many of those tried were effective for a few weeks, or until the first hard rain, after which the trees were immediately attacked.

IT MUST NOT BE EXPENSIVE.

Since a considerable quantity of liquid is required to cover a large log by spraying, it naturally follows that the material must be inexpensive or it can not be used. Creosote oil, the most effective material so far tried, is far too expensive. It can be diluted, however, with as much as 4 parts of kerosene, thus materially reducing the cost of the spray without diminishing its effectiveness. For rustic work a much more costly spray can be used than on logging operations.

IT MUST FIRST PREVENT ALL INSECT INJURY FOR FROM ONE TO THREE MONTHS AT LEAST.

Three months' protection by the spray would be sufficient for most purposes. It is usually possible to get logs to the mill or into a place of safety within that time. If it were sufficiently cheap so that a second and perhaps a third application could be made, the solution would need to be effective for only one month; the necessity for more than one application, however, would of course be a handicap. In many cases three months' prevention of damage would carry the tree or log through the danger period—that in which the insect is flying—and natural seasoning during the ensuing winter would prevent further injury.

EXPERIMENTS WITH PREVENTIVE SPRAYS.

During the period of insect activities in the years 1916 to 1920, inclusive, series of experiments were conducted at the Eastern Field Station of the Bureau of Entomology, East Falls Church, Va., to determine the effectiveness of various solutions. These were

materials recommended by various correspondents or suggested by the forest insect personnel. Dr. J. K. Haywood, chairman of the Insecticide and Fungicide Board, United States Department of Agriculture, also gave some very interesting suggestions.

These experiments are to be considered as only of a preliminary character. The objects were chiefly to determine the requisites of an effective spray and to study the behavior of the different types of insects in relation to various treatments and methods of application, as well as to find an effective spray.

The solutions were tried principally on two kinds of wood—pine and ash—although occasionally hickory, juniper, and oak were used. The wood was cut at a time to give the most favorable condition for insect attack—hickory and juniper about January 1, pine and ash about March 15. It was treated immediately or held in a wire insectary until treated. The individual pieces of wood used were 3 feet long and averaged from 6 to 10 inches in diameter.

Insects of all types were represented in the tests. The following were the most abundant and economically the most important: *Neoclytus erythrocephalus* Fab. on ash and hickory, *Xylotrechus colonus* Fab. on oak and hickory, *Asemum moestum* Hald. on pine, *Cyllene pictus* Drury on hickory, and *Hylotrupes ligneus* Fab. on juniper—all of type 1; *Monohammus scutellatus* Say and *M. titillator* Fab. on pine—both of type 2 (no species of type 2 on other woods); various species of *Ips*, *Phloeosinus*, and *Hylesinus* on pine, juniper, and ash, respectively—of type 4; various species of ambrosia beetles on pine and oak of type 3.

From the foregoing it is seen that pine was tested against all four types; ash against types 1, 3, and 4; hickory against type 1; juniper against types 1 and 4; and oak against types 1 and 3. Owing to the seasonal variations in the abundance of the various species of insects the tests were not conclusive every season. For example, in 1918 and 1919 *Monohammus* was very abundant and attacked all the controls as well as many treated woods, while in 1920 very few were present and not all control logs were attacked. Again, in 1918 *Hylesinus* (type 4) in ash was abundant, though in 1920 very few of the control logs were attacked. Every year, however, some one type was very abundant on all species of wood used.

The flight period of these insects has a certain bearing on the results, as those species flying late in the season found the logs after they were exposed to weathering for a month or more. Most of the treatments were made about April 1, or 15 days before the flight of the first insects, and unless otherwise stated this time of treatment is to be inferred. With certain materials treatments were made also on June 1 at the time of the first flight of some other species. The flight periods are given in Table I.

TABLE I.—*Flight periods of beetles used in experiments for the protective treatments of woods with spray solutions.*

	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Woods.
<i>Neoclytus erythrocephalus</i> , type 1.			—————					Oak, ash, hickory.
<i>Xylotrechus colonus</i> , type 1.			—————					Oak, hickory.
<i>Asemum moestum</i> , type 1.	—————							Pine.
<i>Monohammus titillator</i> and <i>M. scutellatus</i> , type 2.			—————					Pine.
Ambrosia beetles, type 3.	—————							All woods.
Phloeosinus, Hylesinus, and Ips, type 4.	—————							Juniper, ash, pine.
<i>Cyllene pictus</i> , type 1.	—————							Hickory.
<i>Hylotrupes lignus</i> , type 1.	—————							Juniper.

In the extreme northern States the flight period of these insects begins from two to four weeks later. In the Southern States the flight period extends approximately from March 15 to November 1 for all species except *Cyllene pictus*.

Two methods of application were employed—spraying and dipping. Dipping on the whole proved the more effective, as every crevice in the bark was reached; it was also more economical, as a smaller quantity of the solution was required. A round-bottomed galvanized trough requiring only 1 inch of solution in the bottom was used for this purpose. The logs were revolved in the trough until all sides came in contact with the liquid. When carefully done, however, spraying was nearly as effective as dipping and answered very well for practical purposes. It required a fine discharge under strong pressure so that penetration in all crevices was secured.

The treated sticks were placed in several positions: (1) In shaded woods on the ground, (2) in the sun on the ground, and (3) on a platform off the ground in the sun. The location of the sticks had considerable bearing on the results. Those in the woods were always more heavily attacked and those off the ground in the sun least attacked. This can be explained by the more rapid seasoning of the wood off the ground in the sun, which thus offered less favorable conditions for beetle attack, and by the fact that many insects will not oviposit on the upper surface of logs directly exposed to the sun. The logs in the woods were likewise exposed to more humid conditions and the solutions probably leached off sooner. It follows that

the most severe conditions for dipping and spraying tests were presented by those logs in the woods on the ground, and for this reason the discussion of results obtained is based on the results in treated wood placed in this position. Where there was marked difference in the amount of sunlight or in the sun temperature special note is made of the fact.

The thickness of the bark had a certain bearing on the results. Thick-barked pine logs present much more favorable conditions for the attack of all insects concerned. In some cases a treatment was very effective on thin-barked pine logs whereas treated thick-barked logs became heavily infested. The effectiveness of a treatment, therefore, was judged by the results following in the case of thick-barked logs.

TREATMENTS AND RESULTS.

Creosote oil alone.—Pine and hickory dipped and sprayed. No attack three months after treatments except a few insects of type 4 in crevices of sprayed stick.

Creosote oil and kerosene.—All mixtures of kerosene and creosote oil give a tarry precipitate which must be strained out or allowed to settle before the liquid is used in a spray pump. This material was suggested by Dr. A. D. Hopkins.

Equal parts creosote oil and kerosene.—Pine, ash, juniper, and hickory, sprayed and dipped. Results as in the case of creosote oil alone.

One part creosote oil and two parts kerosene.—Treatment as in the next preceding paragraph. Results as in the case of creosote oil.

One part creosote oil and three parts kerosene.—Pine logs dipped. No attack after three months.

One part creosote oil and four parts kerosene.—Pine logs dipped. No attack after three months.

One part creosote oil and eight parts kerosene.—Pine logs sprayed and dipped were attacked after two months by a few insects of type 4.

Creosote oil alone and mixtures of creosote oil and kerosene gave excellent results. Everything considered, much better results were obtained with them than with any other material. Dilutions of creosote oil containing from 1 to as many as 8 parts of kerosene were effective, and perhaps an even greater dilution would be effective on absorbent barks such as ash or juniper. These mixtures act as repellents (in no cases were insects observed to oviposit where the liquid was present) and they "stand up" very well in wet weather.

One part water-gas tar distillate² and three parts kerosene.—Considerably more precipitate results from this mixture than from that of creosote oil and kerosene; consequently it is more troublesome to handle. Pine logs were sprayed and dipped. The results were similar to those with creosote oil.

One part coal-tar road surfacing material and three parts kerosene.—Pine logs dipped with this mixture were attacked after 15 days by insects of type 4 and later their condition was but little better than that of the controls.

² A distillate prepared from water gas.

Coal-tar emulsion (prepared by Insecticide Board); 1 part emulsion to 10 parts water.—Pine logs dipped and sprayed were attacked after 15 days by insects of type 4 and later by those of all types. Final results were no better than in the case of the controls.

Crude petroleum.—Pine logs sprayed and dipped with crude petroleum were attacked by insects of type 4 after 15 days and later by those of all types. Final results were no better than with the controls.

Anthracene oil emulsion (prepared by Insecticide Board); 1 part emulsion to 10 parts water and 1 part emulsion to 100 parts water.—Dipped pine logs were attacked by insects of type 4 after 15 days and later by those of all types. The final results were no better than with the controls.

Crude solvent naphtha.—Pine logs dipped with this material were slightly attacked by insects of type 4 after 15 days and later by all types. Final results were but little better than with the controls.

Six ounces of nitrobenzene in one gallon of kerosene.—Pine logs sprayed and dipped were attacked after 15 days by a few insects of type 4 and later by more of the same type. The final results were somewhat better than with the controls.

Fish oil.—Pine logs sprayed and dipped were immediately attacked by insects of type 4 and later by all types. Final results were no better than with the controls.

Two parts fish oil, one part pine oil, and three parts kerosene.—Pine logs sprayed and dipped were attacked after 15 days by insects of type 4 and later by all types. The final results were no better than with the controls.

Kerosene.—Pine logs sprayed and dipped were attacked after 15 days by insects of type 4 and later by all types; results were no better than with the controls.

Sulphite concentrate (furnished by a paper-pulp mill); full strength and diluted with equal parts of water.—Pine logs dipped were attacked after one week by insects of type 4 and later by all types. Final results were no better than with the controls.

Spent sulphite; full strength and equal parts spent sulphite and a commercial miscible oil.—The results in pine logs dipped and sprayed were the same as with sulphite concentrate.

Tree gum (furnished by Gipsy Moth Laboratory); 1 pound of tree gum dissolved in 1 quart of turpentine.—Pine logs treated with a brush were attacked by a few insects of type 4 after two months. The results were much better than on the controls, but the material held moisture in the log and produced much bluing of sap when insects penetrated the bark. The sticky film acted as a mechanical barrier.

One pound of melted paraffin with one gallon of gasoline added.—Pine, ash, and juniper logs were sprayed and dipped and placed in a cage for experiment against insects of type 4. This treatment prevented all attack on the more absorbent bark of ash and juniper. A few insects attacked the pine.

One-half pound of naphthalene dissolved in one gallon of gasoline.—Dipped pine logs were attacked after 15 days by insects of type 4 and later by all. Final results were but little better than with the controls. The naphthalene soon evaporates and no odor is left.

One pound of melted paraffin with one-half pound of naphthalene and one gallon of gasoline added.—Pine, ash, and juniper sprayed and dipped and placed in a cage against type 4 were attacked by insects of this type after 30 days.

One per cent sodium arsenate solution.—Juniper logs dipped and exposed against insects of types 1 and 4 were not attacked after 60 days.

Sixteen parts of 1 per cent sodium arsenate and one part of a commercial miscible oil.—Juniper dipped in this mixture was not attacked after 60 days, but dipped pine was heavily infested by type 4 after 15 days.

Stock solution of kerosene emulsion, the water used containing 2 per cent sodium arsenate.—Pine and hickory logs, sprayed, were attacked by all types possible. The final results were no better than with the controls.

One ounce of sodium arsenate dissolved in one pint of alcohol and added to one and one-half gallons of kerosene.—Very little arsenate went into solution. Pine logs, sprayed and dipped, were heavily attacked after 30 days by insects of type 4 and later by all types. Final results were but little better than in controls. Ash logs, sprayed and dipped, were attacked by one insect of type 1, but the final condition was much better than with the controls. This treatment was repeated on June 1 under similar conditions and with similar results.

One part arsenic acid to nine parts water followed by lime water (arsenic acid 30 per cent As_2O_5 by weight, S. G. 1.3000, prepared by Insecticide and Fungicide Board.—Pine and ash logs were dipped. The pine was not attacked until 60 days and then by only a few insects of type 4. The ash was not attacked. This treatment, under similar conditions, was repeated June 1, and there was no attack after 60 days.

One-fourth ounce of corrosive sublimate dissolved in two and one-half ounces of alcohol and added to one and one-half gallons of kerosene.—Pine and ash were sprayed and dipped. The pine was first attacked after 40 days by a few insects of type 4; there was no other attack. The ash was not attacked. This treatment, repeated June 1 under similar conditions, gave the same results. Although these logs were not attacked by Monohammus of type 2, it is hardly safe to conclude that this treatment would always be effective against them.

Saturated solution of sodium fluorid.—Pine, ash, and hickory were sprayed and dipped. There was no attack for 30 days, and then the logs were infested by all types, though to a less degree than the controls. Little bluing was noted on pine. Although not altogether successful, this solution is worthy of further trial. This treatment, repeated June 1 with conditions as before, gave like results.

Saturated solution of sodium fluorid, 20 parts to one part of a commercial miscible oil.—Pine logs were dipped and sprayed with results as in the previous experiment.

Three ounces of zinc chlorid dissolved in three ounces of alcohol and added to one and one-half gallons of kerosene.—Pine and ash sprayed and dipped. The pine was attacked after 30 days by insects of type 4 and later by all types. Ash was not attacked by type 1. June 1 the treatment, under the same conditions, was repeated with results as before.

Five and ten per cent crude carbolic acid³ in water.—Pine logs, sprayed and dipped, were immediately attacked and heavily infested by all types. The final results were no better than with the controls.

Two and one-half per cent solution crude carbolic acid in water, eight parts to one part of a commercial miscible oil.—Treatments and results as in the preceding paragraph.

Six ounces of carbolic acid in one gallon of kerosene.—Pine, sprayed and dipped, was attacked after 30 days by all types. The final results were no better than with the controls.

³ Coal-tar oils and acids, 97 per cent; inert matter, 3 per cent.

Carbolic soap solution: One pint crude carbolic acid added to one gallon soft soap, thinned by addition of one gallon of hot water, left to stand overnight, and then diluted with eight gallons of soft water (recommended in literature).—Pine and ash, sprayed and dipped June 1, were attacked by all types after 10 days.

Five per cent solution of nicotine sulphate.—Pine, hickory, ash, and juniper were sprayed, and all were attacked by type 4 within 10 days.

Two teaspoonfuls nicotine sulphate dissolved in three ounces of alcohol and added to one and one-half gallons water.—Pine and ash, sprayed and dipped, were infested by all types after 15 days.

Ten per cent solution of sodium carbonate.—Pine and hickory logs sprayed were immediately attacked by all types possible.

Five per cent solution of a proprietary crude cresol-soap disinfectant.—Pine, juniper, ash, and hickory were sprayed but were all attacked by all types possible.

A strong suspension of whitewash.—Pine logs dipped were heavily attacked after the first rain.

A strong solution of sodium chlorid.—Pine logs sprayed were immediately attacked and their condition was no better than that of the controls.

One part crude pyridin preparation to ten parts water.—This did not mix well. Pine and ash were dipped June 1. After 30 days both woods were infested by all types possible, but were in somewhat better condition than the controls.

One part crude pyridin preparation to ten parts kerosene.—Pine and ash were dipped June 1. After 60 days no insects had attacked either wood. The odor could still be detected on the logs. This material seems to be very promising and deserves further trials.

REMARKS ON POISONS USED.

Several of the more active poisons seem to be effective against certain types of insects, particularly those of type 1. They are especially effective when combined with oils that will penetrate the bark (as the mixture of corrosive sublimate and kerosene) or followed by another solution rendering them insoluble (as arsenic acid followed by lime water). This latter, however, is difficult to apply. They are also more effective when used on absorbent types of bark as ash and juniper.

OTHER EXPERIMENTS WITH INSECTS OF TYPE 3.

The results of the preceding treatments were not conclusive against the ambrosia beetles (type 3) for two reasons: These insects require wood that is moist—at least such wood presents optimum conditions—in which to rear their broods. The logs used in the preceding experiments, averaging only 6 to 10 inches in diameter, often dried so rapidly that they were not suitable for these beetles. At the same time another series of experiments was being conducted in which water-soaked logs were used. These acted as traps, attracting most of the ambrosia beetles.

Consequently, to determine just how effective these solutions were against ambrosia beetles (Table II), the water-soaked logs were thoroughly sprayed with (1) 4 parts kerosene plus 1 part creosote oil, (2) the corrosive sublimate solution as given before, and (3) 1 part crude pyridin preparation to 8 parts kerosene. All the sticks were dried for 24 hours before the sprays were applied. These materials were applied to three pines, one oak, and one ash log, July 28, 1920. The results are given in Table II.

TABLE II.—*Results of experiments in the treatment of water-soaked logs against ambrosia beetles.*¹

	Controls.			Kerosene and creosote oil.			Pyridin and kerosene.			Corrosive sublimate.		
	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.	Pine.	Oak.	Ash.
Aug. 3.....	1	1	7	0	0	0	0	0	0	0	0	1
9.....	0	1	23	1	0	0	0	0	1	0	0	3
13.....	1	3	27	0	0	0	0	0	0	0	5	6
22.....	5a	x	x	0	0	1	0	1	0	1a	4	16
27.....	1a	13	64	1	0	0	0	0	0	1a	0	10
Sept. 1.....	(2)	(2)	(2)	0	0	0	0	0	0	0	0	4
8.....	0	1	4	3a	0	0	0	0	1	2a	1	7
18.....	(2)	(2)	(2)	0	0	2	9	0	0	0	0	1
28.....	(2)	(2)	(2)	0	0	1	0	0	0	0	0	4
Total ambrosia beetles.....	2	19	125	2	0	4	0	1	2	1	10	52

¹ Numbers refer to ambrosia beetles attacking except when followed by letter.

² Not counted.

a=species of *Ips*, type 4. x=many ambrosia beetles not counted.

POISONING OF AMBROSIA BEETLES.

To determine whether ambrosia beetles feed on the bark as they bore through it, and consequently whether poison spray could be effective against them, several water-soaked ash logs were dried for 48 hours to remove the excess water from the bark and then completely submerged for 48 hours in a solution of sodium arsenate, 2 pounds to 10 gallons of water.

A wooden frame with a cheesecloth bottom was prepared on the ground, and on supports above this frame a rubber cloth was suspended to keep any rain from reaching the treated sticks. The sticks were placed in the box on the cheesecloth and the cloth was carefully examined every two or three days for dead ambrosia beetles. The treatments were made on May 30, 1920. An untreated control was used in the same position. The results were as follows:

June 8, one dead beetle beneath sticks.

June 15, one beetle boring through bark.

June 23, two beetles boring through bark.

July 23, two to six beetles were in each stick and all galleries contained eggs and various stages of larvæ.

These beetles were evidently not deterred or injured by the poison. At no time were the sticks wet. It is quite probable that the dead beetle found June 8 was not killed by the poison, since no other dead insects were found.

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EFFECT OF LOW TEMPERATURE ON THE HATCHING OF GIPSY-MOTH EGGS.

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INTRODUCTION.

Extensive study of the gipsy moth (*Porthetria dispar* L.), made in connection with the introduction, establishment, and dispersion of its parasites, has shown that in New England there are agencies of natural control responsible for a considerable mortality among the various stages.

One of these natural-control agencies, which in many cases is the most valuable, acts upon the eggs and causes a failure to hatch. This phenomenon has been termed nonhatch. The results of several years' study are presented in this bulletin.

PRELIMINARY DISCUSSION.

The failure of gipsy-moth eggs to hatch has been common enough to attract attention during the last few years only. As will be shown later, very low temperatures are responsible for this killing, and until about 10 years ago the moth had not spread into territory having such low temperatures regularly. It is probable that even in the older infested area there were isolated pockets which, owing to topography, attained temperatures low enough to kill. Likewise it is probable that a careful examination of some of the egg clusters which

apparently hatched well would have shown considerable injury. Such points, however, would only have been brought out by an intensive study in the woodland, such as was started later. A few records of entire clusters failing to hatch were made in 1907, notably in North Saugus, Mass., in woodland near the building then used as a laboratory for the parasite investigations.

During the winter of 1911-12 plans were perfected for an extensive and intensive study of the gipsy moth under natural conditions. These plans called for the selection of a considerable number of small areas, well proportioned as to type of tree growth and so placed as to be representative of the entire infested area. The areas designated as "observation points" were to be followed closely during the entire year, with careful notes on hatching of the gipsy-moth eggs, feeding of the larvæ and the injury done by them, the increase or decrease of the infestation from year to year, and many other phases of the subject. As the entire problem was built around the degree of infestation, it became necessary to have an accurate knowledge of the number of egg clusters present in each "point." Therefore, each fall or winter a careful count was made, and it was this counting which brought forcibly to the attention of those engaged in experimental work that some agency was playing a considerable part in the control of the moth by killing the eggs.

The nonhatch problem did not receive extensive experimental attention until the fall of 1915, when preliminary work was started.

FIRST INVESTIGATIONS.

At first considerable time was devoted to the study of the nonhatch eggs themselves. Such individual eggs collected a few months after the end of the normal hatching season, as well as those 1 or 2 years old, were all light gray in color. Careful dissection showed that this appearance was due to a complete, closely woven mat of fungus mycelium which was pressed closely against the inside of the shell and entirely surrounded the dead embryo. The presence of this organism in all the nonhatch eggs made it appear that there might be some connection between it and the death of the embryo. Cultural studies were made, and a considerable number of infection experiments were carried on, which, however, failed to give more than vague evidence that the fungus was ever more than a saprophyte. It is possible that this organism, belonging in the large and rather indefinite genus *Fusarium*, is, under conditions particularly favorable to itself, a true parasite. However, extensive dissections and cultures made of nonhatched eggs as soon as it was shown that they were not going to hatch have yielded no positive evidence of its being parasitic.

The first real study of nonhatch in the field was begun in the fall of 1916.¹ Previous to this a series of egg-cluster collections had been made, beginning in August, 1915, and continuing at monthly intervals until just before normal hatching time in the spring of 1916. Six sets of these collections were made, five being obtained at chronic

¹ The writer wishes to express his appreciation of the able assistance given him by Mr. H. I. Winchester, who helped with the experiments for almost the entire time they were conducted. During the time the writer was in the Army, Mr. Winchester conducted all the experiments, and to him belongs the credit for planning and making the summer observations on hatching.

nonhatch points—that is, points at which considerable nonhatch had been noted each year since the start of the “observation-point” investigations. The sixth set, collected as controls, was obtained from a point which had not shown nonhatch. All the clusters thus obtained were kept in a cool place at the laboratory from the time of collection until just before normal hatching time in the spring. Each cluster was then placed in a glass tube and allowed to hatch normally. All larvæ thus produced were counted, and later, when hatching had ceased, the remains of the clusters were rubbed over a cheesecloth sifter to separate the unhatched eggs from the hair with which the egg cluster is made.

As soon as the records from the six sets of collections could be studied it was seen that there appeared to be some connection between nonhatch and cold weather, for clusters obtained from the five points before our normally cold months hatched almost perfectly, while those obtained after the cold season began failed to produce larvæ.

This suggestion opened up a new line for investigation, and accordingly three sets of weather instruments, each consisting of a recording thermometer and a recording hygrometer, were procured and placed in small instrument houses. As the instruments required considerable attention the three houses were placed at points in the towns of Westford, Acton, and Dover, Mass., two being chronic nonhatch and the third no nonhatch, not very many miles from the Melrose Highlands Laboratory.

The instruments were started September 1, about the end of the laying season, and were run continuously until about May 1, the normal hatching time. They were tested for accuracy at frequent intervals to insure true records, a discussion of which will be given later.

METHOD OF HANDLING ALL EGG CLUSTERS USED IN EXPERIMENTS.

Egg clusters when brought in to the laboratory were placed where they would be kept cool but not exposed to severe weather. Just before normal hatching time, which is about May 1 at Melrose Highlands, each cluster was placed in a glass tube large enough to contain it unbroken. This tube was closed with a cotton plug. As soon as hatching was well advanced, the larvæ were removed from the tubes and counted. At the end of the hatching season, the remains of each cluster were rubbed over a cheesecloth sifter, made by stretching fine-meshed cheesecloth over a frame, to separate the unhatched eggs from the mass of hair with which all clusters are made. These unhatched eggs were then examined microscopically and divided into infertile and nonhatch, the records of each cluster being kept separately.

MONTHLY COLLECTIONS.

Some of the clusters collected during the season of 1915-16 proved to be old nonhatch. During the winter, after the new clusters have become weathered, it is difficult to distinguish between old and new. To make certain that only new clusters would be collected, a sufficient number of these were marked with lumber crayon at the end of each laying season at the same six points used for the collections

of 1915-16. Ten clusters were collected at each point on the first of each month, beginning in September and ending in April. Subsequently they were handled exactly as described.

As the sets of weather instruments were located at three of the collection points, the records obtained from these are the most valuable. The other three, however, were kept as collection points for purposes of comparison.

MONTH'S EXPOSURE.

As controls on the naturally produced egg clusters obtained in "monthly collections," a series of experiments were conducted with clusters produced at the laboratory. To obtain these, vigorous males and females were mated in a small cage, and later the females were confined in small tin boxes, where they deposited their eggs upon pieces of thin wood.

Ten such clusters were tacked to trees at each point where there were weather instruments and allowed to remain in the open just one month. The first set was out from September 1 to October 1, the second from October 1 to November 1, and so on. The last set placed out April 1 was brought in just before hatching time. After exposure the clusters were handled as in all the other experiments.

NATURAL PROTECTION.

Notes taken in connection with the "observation-point" investigations showed that in certain localities there was considerable difference in hatching on different parts of the trees. Clusters found under roots or in cavities close to the ground, as well as those fully exposed close to the ground, appeared to hatch completely, while those higher up failed to do so.

Investigation at a number of chronic nonhatch points proved that in general it would be rather difficult to find enough clusters naturally deposited where they were wanted. Therefore, at each of the six points from which monthly collections were obtained 100 new clusters were cut from the trees and tacked back in the following positions:

Twenty-five clusters were tacked under roots or in cavities close to the ground. Usually these were covered with leaves.

Twenty-five at the base of a tree close to the ground but entirely in the open.

Twenty-five on the trunk well up from the ground, usually about 5 feet.

The remaining 25 were brought in to serve as controls.

Collection of these clusters was made just before hatching time each spring.

ARTIFICIAL PROTECTION.

Originally these experiments were planned when the fungus found in the nonhatch eggs was looked upon as a possible cause. Various means were tried of protecting the clusters against infection, but most of these were abandoned when the true nature of the fungus became apparent.

Two experiments in artificial protection were continued. The first, by means of a wire cage suspended between trees, sought to protect the clusters contained therein from any influence the tree

might have and at the same time expose them fully to all actions of the elements. The second was an endeavor to protect the clusters from wind and rain or snow, but to expose them to fluctuations in temperature and atmospheric moisture. This was accomplished by placing them in open inverted preserving jars and holding them up near the bottom with wire screen. The jars were wired to tree trunks.

Both types of artificial protection were performed with laboratory-bred clusters and were put out at a considerable number of chronic nonhatch points. The clusters were brought to the laboratory in the spring and handled like all the other experimental clusters.

EXPOSURES OF CLUSTERS TO ONE SEVERE DROP IN TEMPERATURE.

After results from some of the other experiments had pointed rather conclusively to low temperatures as the cause of nonhatch, it was desirable to gain more information on the degree of cold and the extent of exposure necessary to kill.

It was planned to expose sets of clusters to a single severe drop, beginning with -15° F., apparently the temperature at which the first killing took place. It was hoped that a complete chain would be obtained from -15° downward as far as the thermometer goes at the points where the weather instruments were placed. This was not found to be possible, as one could not foresee the temperature fluctuations. A certain number of such sets of clusters, however, were exposed.

The sets of laboratory-bred clusters were placed near the weather instruments and allowed to remain until they had been exposed to a single drop of at least -15° . They were then brought in and handled like other clusters.

TEMPERATURE RESISTANCE.

Sets of 10 laboratory-bred clusters were exposed during the winter in small wire cages along the line marking the northern limits of the gipsy-moth area. These were placed in towns from which the Weather Bureau office at Boston obtains records, so that a close record of the cold might be available, for it was desired to note the effect of as extreme cold as possible.

These remained out all winter until just before hatching time, when they were brought to the laboratory.

SUMMER SURVEY OF HATCHING.

Each summer for three years, after the hatching season was over, an extensive series of observations on hatch was made in the field. Practically the entire area of infestation was gone over from the most southern limits to the most northern, and a very large number of observations were made. Fortunately it was possible to make these observations after two very cold winters and one very mild one, the latter coming between the two cold ones.

WEATHER.

The instruments located at the three points gave records of temperature and relative humidity. As soon as these records for the

first year could be compiled and studied it became evident that humidity could play little, if any, part in the killing of the eggs. As stated elsewhere, the factor responsible for nonhatch acts during the cold months of December, January, and February, during which the amount of moisture in any given space is very low. This in itself would hardly be proof, as low humidity might have some effect. There was no appreciable difference, however, between the humidity records from the three points, two of which showed nonhatch while none was obtained from the third. Humidity records for succeeding years have only served to substantiate those obtained the first year.

Temperature lines for the three points followed one another closely until December, but as soon as severe cold weather set in the difference became very marked.

At the point which had never yielded nonhatch the coldest days found the mercury little below zero, while at the other two, temperatures of from -20° F. to -30° F. were recorded, and during most of the time they were from 15° to 25° colder than the first point. The two exceptions to this were during December, 1917, and February, 1920, when the temperature at the warmest point fell to -15° and -16° F., respectively, for the only times during the four years that records have been taken. These resulted in many eggs failing to hatch.

Temperature records obtained from the instruments during four consecutive winters show that the cold weather comes from the last part of December to the first of March, with the lowest drops in January and February. The first winter, 1916-17, was only moderately cold, with the greatest drop coming in February. The next winter, 1917-18, was extremely cold in December, January, and February, and following this came the unusually mild winter of 1918-19 with hardly a drop below zero. This in turn was followed by another extremely cold winter which made conditions almost ideal for our experiments. The mild winter of 1918-19, coming as it did between two that were very cold, made comparison of the records of all three seasons very valuable.

The Weather Bureau office at Boston obtains records regularly from 50 substations in the gipsy-moth area. A study of these records shows that in general the drops in temperature become lower as one goes northward. Along the coast, however, due to the modifying effect of the ocean, the cold is nowhere nearly as severe as it is farther inland. Also, one may find small areas having much lower temperatures than the surrounding country, due to the topography which induces that phenomenon known as air drainage, the cold air flowing down into the lowest spot and settling there.

RESULTS OBTAINED FROM EXPERIMENTS.

Monthly collections, as stated on page 3, were made at five chronic nonhatch points and one control point where no nonhatch had ever been found. Three of these had weather instruments, so that it was possible to check results against temperature records.

Collections made at the nonhatch points up to February 1, 1917, the only month having severe cold that winter, hatched completely, while those obtained March 1 and afterwards were all nonhatch. Those laboratory-bred clusters exposed during the month of February were all killed, but those exposed every other month hatched completely. The next winter severe cold came in December, January, and February. Collections made up to December 1 gave complete hatch, while neither those collected after that date nor the month's exposure clusters for the three cold months hatched. The next winter, 1918-19, was mild, and all clusters for all months hatched completely. The winter of 1919-20 was another very cold one, with the extreme cold coming in January and February, resulting in hatch records identical with those of the other cold periods for both monthly collections and month's exposure.

During the entire four winters only two drops greater than -10° F. were recorded from the point which had never shown nonhatch. The first, in December, 1917, -15° , resulted in about 50 per cent of the eggs in the monthly collections and month's exposure clusters being killed. The second drop, -16° , came in February, 1920, with the same effect on the eggs.

The method employed in determining the extent of injury to the eggs in the various experiments may need explanation. In the first place, care was taken to provide plenty of control clusters for all the experiments and these were treated exactly like those for which they were controls, except that they were not exposed to conditions at the various points. Clusters which did not hatch at all could be listed as complete nonhatch. However, in figuring percentage of hatch in partially hatched clusters, the number of infertile eggs was deducted first, as they could not possibly have hatched.

A careful comparison of the temperature and nonhatch records has led to the conclusion that -20° F. is about the highest point at which all the eggs in a cluster will be killed and a further drop will make it more certain that all exposed eggs will be killed. There is reason to believe that the resistance of the eggs depends to some extent upon their vitality, as would be only natural. Evidence on this point was secured from the sets of clusters which were only exposed to a single severe drop in temperature. One set exposed to -22° F. was entirely killed, but a very few eggs in a set exposed to -23° F. hatched.

There are no records of any eggs hatching after being exposed to a temperature of -25° F. or lower, whether they were subjected to one such exposure in the "single drop experiments" or several, as sometimes happened with the "month's exposure" sets. On the other hand, exposures to -15° and -16° F. killed half the eggs in the clusters, but no temperature above -20° F. killed an entire cluster. Various records of exposure to temperatures higher than -15° F. showed no injury at all.

The conclusion, therefore, is that the vital point for complete killing lies between -20° and -25° F., with an absolute certainty that all eggs exposed to any further drop will be killed.

The artificial protection experiments may properly be considered after the monthly collections and month's exposure, for the data secured from the first in a way serve to substantiate those ob-

tained from the last two. All of these were conducted at chronic nonhatch points.

Those clusters placed in the wire cages were entirely removed from any influence the trees might have upon them and were fully exposed to all actions of the elements. Very little information was obtained from this series beyond the fact that clusters reacted the same way no matter how they were placed.

During the cold years all of these clusters were killed, as were those naturally on the trees. After the mild winter they all hatched completely.

Those clusters in the inverted jars received a considerable amount of protection, as they were in no way affected by storms. Low temperature could act upon them freely and to a certain extent the atmospheric moisture could do so, for the jars were open at the bottom, allowing air to ascend into them when it became warm. No rain or snow could reach them, however, and as a result they remained perfectly dry during the entire winter, as was proved by numerous observations. They were therefore not frozen or covered with ice, as were many of the clusters in the open.

These clusters were only exposed to temperature and atmospheric moisture. It has been shown already that humidity can play very little, if any, part in killing the eggs; therefore it may be considered that if these eggs were killed temperature must have been responsible. To corroborate this conclusion all eggs exposed in this manner failed to hatch after the cold winters, but hatched perfectly after the mild one.

Experiments in natural protection were suggested by notes taken in connection with the "observation point" investigations, as has already been noted. It was found that those placed close to the ground at nonhatch points, whether in cavities, under roots, or in the open, hatched completely, while those high up were killed. At first sight snow appeared to be the protecting factor; and this supposition was borne out later by actual observation, though it was some time before all variations could be reconciled with this theory. To afford protection the snow had to cover the clusters during every severe cold spell, which it did not do because of the countless variations in its depth, and it was only after a long series of observations in the woods that a true appreciation of the variableness of this factor became apparent. Depth even immediately after the cessation of a storm varied enormously, particularly if the snow was light, for every breath of air induced drifting. Many times also the eddying of the wind around the tree trunks left the snow piled against one side and blown away from the other. The resulting depression served to expose some clusters while others remained covered, a fact which explains why clusters close to the ground were killed and those much higher hatched.

A close following of the snow history of a section during the winter showed great fluctuations in depth, when measured on the trunk of a tree small enough to be unaffected by the wind eddies mentioned above. At the end of a storm the snow would be piled to a certain height on the tree; then gradually settling would take place, until after the lapse of a few days there would be several inches difference

between the new level and the old. A new storm might then come and cause the level to rise again. So it went during the entire winter, and clusters on the border line of snow protection were alternately exposed and protected. Observation made on some such clusters proved conclusively that the snow is the medium of protection.

There remains only one series of experiments to be discussed, namely, temperature resistance, which was conducted for two years only. As it developed, the first year selected for this type was, very opportunely, the mild winter 1918-19. The only killing of eggs for that year that was recorded in our experiments developed in some of these sets of clusters exposed at the northernmost limits of the gipsy-moth area, in the only towns from which records anywhere near -20° F. were taken. After the next winter, as was to be expected, none of the clusters in this series hatched.

RESULTS OF SUMMER SURVEY OF HATCHING.

A few observations made in the field after the end of the hatching season which followed the extremely cold winter of 1917-18 disclosed the fact that there was an unusual amount of nonhatch. This gave a very good opportunity for a careful study under natural conditions. Accordingly, extensive plans were made to extend observations over as large a portion of the gipsy-moth area as possible. Results obtained from experiments had pointed strongly toward low temperature as the causative factor of nonhatch. To a certain extent, however, the experiments had an element of artificiality, and it was desired to obtain as much information as possible under purely natural conditions.

The plans called for observations on hatch of egg clusters on trees, undergrowth, stumps, debris on the ground, boulders, stone walls, and other objects. Many factors were taken into consideration, such as nearness to the ocean and bodies of fresh water, height of land, degree of exposure to prevailing winds, favorability or unfavorability of food plants and the abundance or scarcity of these, the degree of gipsy-moth infestation, and any other points which might present themselves. These observations were taken during the three summers 1918, 1919, and 1920.

The observations taken in the summer of 1918 disclosed a complete nonhatch of all clusters above the snow-protection line in Maine and New Hampshire, with the exception of a section along the seacoast. This section showed only a partial hatch. All clusters found on the ground or on other objects close to the ground where they could be snow-protected hatched completely. Hatching above the snow-protection line in Massachusetts, with the exception of a coastal section which included all of Cape Cod, was poor with a considerable number of whole clusters killed, particularly in the northern and northeastern parts. Hatching of low clusters in all this area was uniformly good.

In Rhode Island and along the coast as far north as the Massachusetts-New Hampshire line the hatch was almost complete.

Apparently the modifying influence of the ocean overcame the severe cold at least enough to prevent the temperature from dropping to the killing point all along the coast of Rhode Island and Massa-

chusetts. The area over which this modifying effect protected the eggs was wide in Rhode Island and Massachusetts, but it gradually narrowed northward until at Portsmouth, N. H., the only modification was right on the coast, and even there some of the eggs were killed. Farther north the cold was too great to be overcome sufficiently to allow the egg clusters to hatch completely, and only a partial hatch was recorded.

The Weather Bureau records show that the foregoing hatch records are just what would be expected if low temperature was the cause of nonhatch.

Bodies of fresh water apparently had no influence on the hatch.

Elevation made no difference except in sections right on the border line of killing cold, that is, sections which as a whole had temperatures not quite low enough to kill. In these sections clusters in low areas were killed while those on the higher levels escaped, a difference caused by cold draining into the low land and settling there.

The object upon which the clusters were placed had no effect, as no matter what it was, if they were above snow protection in a locality which had severe cold, they were killed.

Considerable observation on the possible influence of the food plants failed to show any difference. Records taken in any locality were uniform no matter what species of tree the eggs were laid upon, and irrespective of the abundance or scarcity of favored food. Of course this latter factor had some bearing on the abundance of clusters, but it made no difference in the nonhatch.

At only one place, a location right on the coast in Rye, N. H., was it possible to make a direct comparison between egg clusters completely exposed to the prevailing winds and others well protected from them. In a little grove about a quarter of a mile from the sea, exposed on its ocean side to the full sweep of northeast storms, the clusters on the windward side had the hairy covering entirely weathered away, leaving the eggs uncovered. These did not hatch. On the other side of the same grove other clusters were found which had not been deprived of their hairy covering. These hatched almost perfectly.

Following the mild winter of 1918-19, the same localities were visited again. Every cluster found, no matter what its position on the tree or other object, hatched perfectly. In fact, there was not a single nonhatch cluster found during the progress of the summer survey; neither was there one reported by men engaged in other branches of the gipsy-moth investigations.

The winter of 1919-20 was a complete contrast to its predecessor but was almost exactly the same in temperature as that of 1917-18. There was a considerably greater fall of snow in some localities, which gave protection to a greater number of clusters. Observations after this winter gave the same results as those after the other cold one, except that in some places which had more snow than during the other cold winter a greater number of clusters had hatched.

All of the results of the summer survey observations, compared with records of temperature obtained by the Weather Bureau, serve to add conclusiveness to the fact that low temperature is the cause of nonhatch.

EFFECTIVENESS OF NONHATCH.

Nonhatch as an agency in the natural control of the gipsy moth reaches the maximum of its importance in those sections of the infested area which have, some time during each winter, cold severe enough to kill all eggs exposed to its action.

The principal protection from this killing cold is afforded by the snow; and the upper limit of this protection, measured from the ground, has been designated as the snow-protection line. It must not be supposed that this line has any definite limits, for the depth of snow is an extremely variable factor.

To determine the value of nonhatch as an agency in gipsy-moth control it is therefore necessary to determine the distribution of the egg clusters on the trees, the factors which influence this distribution, and the proportion placed above the snow protection line. Fortunately a considerable amount of information along these very lines has been obtained during the progress of the "observation point" investigations.

The count of egg clusters made at each "point" was divided into two sections. The dividing line was marked at 5 feet from the ground on the trunks of the trees. The count of clusters above this line was known as the high count, of those below as the low count. Such a division was necessary on account of the work involved, which made impossible the complete counting of an entire point at one time. Many times also snow would prevent a low count but would not prevent the high count being taken. Five feet was chosen as a convenient point well above the usual snowfall.

As the clusters were recorded with reference to their position above or below this 5-foot line, it will have to be the dividing line considered in studying the distribution of clusters on the trees. A depth of snow to the extent of 5 feet is almost unknown in most sections of the gipsy-moth area, so we may safely consider that all the exposed egg clusters above 5 feet will be killed if the temperature drops to -20° F. or lower. At the same time there will probably be a considerable number of clusters between the 5-foot level and the top of the snow during at least one period of severe cold, so that we are conservative in using the high count as a basis for figuring benefit derived from nonhatch.

A careful consideration of the egg-cluster records from the "point" notes, which were taken during seven consecutive years, shows that on the average 70 per cent of the clusters are laid above 5 feet. An average of nearly 900 individual counts showed 72 per cent.

The deposition of clusters is influenced largely by the ground conditions. If there is no underbrush and if debris, such as dead wood, bark, etc., is not present or if the ground is wet, most of the clusters will be well up on the trees. On the other hand, if debris is abundant, if there is much undergrowth, or if, as often happens in New England, there are stone walls running through the woods, a large proportion of the clusters will usually be found close to the ground.

It is not possible to say just what causes the differences, but the "point" notes show that they are as stated. In addition, the records

show that unless some change takes place, such as removing the débris or increasing it by brush from cutting, the proportion of those above and below the 5-foot line will remain approximately the same. Having determined 70 per cent as being the average proportion of egg clusters laid above 5 feet, we can see just how valuable as a means of control nonhatch may be where the cold is sufficiently severe to kill all unprotected clusters.

This particularly desirable state of affairs can not be looked for in a large part of the territory, for the temperature does not go low enough. The "point" notes show all variations between the above-mentioned percentage and no killing at all. Occasionally there is a mild winter with no low temperature and all eggs hatch the following spring.

As nonhatch is caused by a temperature of from -20° to -25° F. we can only expect to find it in territory subjected to such low degrees. Temperature records obtained from the 50 stations of the Weather Bureau which are located in the present area of infestation show that any prophecy as to just what would happen in any locality would be quite useless. If the law of averages may be considered in this case, killing cold will occur in a majority of years in all of Maine and New Hampshire except a narrow area along the coast. In Massachusetts such cold, at least as reported by the weather stations, is the exception, but there appears to be a greater tendency toward it in Worcester County and the northern part of Middlesex County. The remainder of the infested area, with the exception of the northern part of Windham County in Connecticut from which extreme low temperatures are occasionally reported, apparently escapes cold severe enough to kill the eggs.

These general conclusions, based as they are upon Weather Bureau records, apply to the sections as a whole. Local conditions, however, vary to such an extent that we may find nonhatch in restricted areas in sections from which temperature records would apparently exclude it. "Observation point" investigations prove this to be particularly true of northern and central Massachusetts.

It is possible that nonhatch is responsible for the slow increase of the gipsy moth in many localities where food conditions would seem to point to just the reverse.

EFFECTS OF COLD ON PARASITES.

There is reason to suppose that a drop in temperature low enough to kill the eggs will have some effect upon the imported parasites, particularly those which attack the eggs themselves. Two egg parasites, namely, *Anastatus bifasciatus* Fonsc. and *Schedius kuvanae* How., have become well established in New England. The former passes the winter as a full-grown larva within the egg of the host. No collections of eggs parasitized by *Anastatus bifasciatus* have been made after extremely cold weather for the specific purpose of determining the effect of cold upon this parasite. It was noted, however, that there was a large percentage of dead parasites in a bulk collection of eggs obtained after the cold winter of 1917-18. The locality from which this collection came has been used for a number of years as a source of material for new colonies, and eggs

collected there had each year shown a high percentage of parasitism. After the above-mentioned cold winter the parasitism was of decidedly lower percentage, but two years later it had about reached its former high point.

In the long run it is doubtful if the cold would have any very serious effect upon the general abundance of *Anastatus bifasciatus*. Even though all the parasites as well as all the eggs above the snow protection line were killed, the proportion of parasites to eggs would be the same in those egg clusters protected by the snow, for there is very little difference in percentage of parasitism between eggs near the ground and those above 5 feet. Therefore, there would be the same proportion of adult parasites to attack the eggs the next summer as if all parasites and all eggs came through the winter safely.

As the result of particularly adverse conditions a decrease in parasitism by *Anastatus bifasciatus*, such as was evidenced at the stock colony, may occur for a few years, but no doubt there is a gradual recovery.

Schedius kuvanae has received some rather severe setbacks from cold winters. It hibernates as an adult, principally in leaves and rubbish on the ground, and in such position it would be well protected from the cold if there was plenty of snow during each period of extremely low temperature. Apparently such protection has not been present in a number of cases, for there are records of colonies from which recovery of parasites was difficult after a severely cold winter.

Some of the other imported parasites may be killed by low temperature, but very little information has been obtained to confirm this idea.

Further investigations may throw more light upon the relationship of low temperature to parasite mortality.

CONCLUSIONS.

The failure of gipsy-moth egg clusters to hatch is caused by low temperature.

An exposure of between -20° and -25° F. is necessary to kill entire clusters, though some eggs in each cluster may be killed by an exposure to -15° . No eggs will survive an exposure to lower than -25° .

When the temperature is low enough, an average of 70 per cent of the clusters may be killed, but this desirable condition develops only in the northern part of the infested area and only during certain years.

Snow will protect the egg clusters from the effects of the cold if it covers them; therefore, the greater the depth of snow the larger the number of clusters that will hatch the following spring.

The benefit derived from nonhatch may vary after a cold winter from 70 per cent of the clusters killed in the northern part of the area to no injury to the eggs in the southern section.

Maine and New Hampshire receive the greatest benefit from nonhatch. Central and northern Massachusetts also derive considerable benefit particularly in restricted localities. Connecticut, Rhode

Island, the southern and eastern parts of Massachusetts, and the coastal section of New Hampshire derive very little, if any, benefit, for even after the coldest winters nearly all eggs hatch.

Nonhatch is of a periodic nature, as occasionally New England is visited by a mild winter, after which practically all eggs hatch.

The benefit derived from nonhatch is offset to some extent by the injury cold weather works upon the parasites of the moth.

As temperature is entirely uncontrollable, there is no way that man may direct its action against the gipsy moth.

Finally, too much reliance must not be placed on nonhatch as a means of control, for it occurs only after the egg clusters have been exposed to the proper degree of cold.

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PROFESSIONAL PAPER

JULY, 1922

BIOLOGY OF THE PAPAYA FRUIT FLY, *TOXOTRYPANA CURVICAUDA*, IN FLORIDA.

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INTRODUCTION.

The occurrence in 1905 of a newly introduced species of fruit fly (*Toxotrypana curvicauda* Gerst.)¹ attacking the papaya (*Carica papaya* L.) in south Florida was the occasion several years later for a preliminary investigation and paper on the insect by Knab and Yothers.² Technical descriptions of the insect, together with its distribution and history, are recorded therein, and also some notes on its habits. In recent years the pest has assumed much greater economic proportions, due to the increasing production of the papaya from a commercial standpoint, and also to the spread of the insect over nearly all portions of the State where papayas are grown. Hence a careful study of its biology and control was undertaken by the writer.

It is the purpose of this bulletin to present an accurate account of the life history and seasonal history of the insect, together with its habits and the factors influencing its development and spread. The methods of control as far as worked out are also given.

¹ Dipterous family Trypetidae.

² Knab, Frederick, and Yothers, W. W. Papaya fruit fly. In Jour. Agr. Research, vol. 2, No. 6, p. 447-454, pl. 41-42. 1914. Literature cited, p. 453.

DESCRIPTION AND LIFE HISTORY.

EGG.

The eggs (Pl. I. C. *b*) are of very unusual proportions, being long and slender, somewhat club-shaped or fusiform, with a long cylindrical stalk. The average length is about 2.5 mm. and the greatest diameter is 0.2 mm. They are inserted into the seed cavity of the fruit from the long ovipositor of the female. The stalk sometimes remains partly in the flesh, although the eggs are never placed there as the young maggots seem unable to survive there. They always occur in clusters, and usually there is only one cluster to a fruit. The cluster consists of from 6 to 20 or more eggs, which are always fastened together by an adhesive substance on the surface of the eggs. One female, according to Knab and Yothers, is capable of laying 103 eggs, all of which are disposed of at about the same time.

The eggs require from 12 to 14 days to hatch at any time throughout the year. Although the other stages are longer in winter than summer, the egg seems not to be affected by climatic changes. This point was determined by cutting open infested fruits at definite intervals after they were stung. Usually an adult would oviposit in several fruits on a tree the same evening. It was then possible to cut one of these on each of several successive days until the eggs were found to have hatched. Even in the fruits which had been cut the eggs would complete their development if the halves were placed together, provided they were several days old when first exposed to the light and air. With freshly laid eggs this was not found to be true. Many attempts were made to rear the eggs artificially after removing them from the fruit but without success. When dissected from the fruit and placed on a piece of leaf or fruit pulp over a plug of wet cotton in a vial inverted in water, as practiced by Back and Pemberton³ with melon-fly eggs in Hawaii, they failed to develop. Even though the conditions of heat and moisture were apparently the same as in the fruit they did not hatch.

When ready to hatch the eggs split longitudinally along the micropylar half and the maggot escapes, leaving the stalk end intact.

LARVA.

The young maggots on hatching from the eggs begin at once to feed on the coating of the seeds. They remain for about the first half of their existence within the seed cavity, feeding on the seed coverings and other fibers there. Many of the seeds become de-

³ Back, E. A., and Pemberton, C. E. The melon fly in Hawaii. U. S. Dept. Agr. Bul. 491, p. 18. 1917.

tached by this process, and the loose seeds in the fruits serve as an indication of their presence. When newly born the maggots are almost transparent, but soon assume a shining, dirty white color while in the seed cavity. Later on, as they continue to develop, they eat into the flesh of the fruit, first close to the cavity and then working farther out until, when mature, they are close to the skin. They have then only to eat a hole through the rind to escape. During this latter part of their life they become a rich golden yellow color, like the color of the fruit on which they are feeding. The presence of the maggots in the fruit usually causes it to turn yellow and ripen prematurely. This is a distinct advantage to the larvæ, for they do not like the juice of the green fruits and usually remain around the seed cavity until the flesh begins to soften.

The mature maggots (Pl. I, C, *a*) average about 11 mm. in length, are subcylindrical in shape, and taper anteriorly to the mouth.

The length of time required for their development varied from 10 to 27 days in a large number of tests. The cooler weather of winter prolongs somewhat the length of the larval stage. Conditions unfavorable to the larvæ, such as the fruit decaying or the maggots being removed from the fruit, will cause them to transform before the normal time. On the other hand, if the conditions are favorable the larvæ may remain in the fruit for several days after reaching maturity. The average time for this stage is 15 days.

They make their escape by eating a hole through the skin and dropping to the ground. As a rule, when one escapes the others will follow in rapid succession, and often all emerge from the same exit hole. If the fruit has already fallen from the tree the maggots go into the ground immediately under it; if the fruit is still on the tree they drop to the ground. Often a larva will remain partly emerged from a fruit and continue a wriggling, twisting motion for an hour or more before finally dropping. When once on the ground the maggots immediately bury themselves and never wander around on the soil. The transformation is completed within a few hours after entering the ground. The period of exposure from the time of leaving the fruit to entering the soil ordinarily would be only a minute or two, and consequently there would be little chance for parasitism here. Very rarely a maggot will pupate inside a fruit.

The number of maggots in a single infested fruit sometimes runs up as high as 40, although ordinarily there are about 15 or 20. A very small fruit may have only 2 or 3.

If confined in breeding jars where no soil is present the larvæ usually will not pupate. In a glass stender dish or Petri dish the mature maggots would remain in the larval stage for three or four days, continually crawling around the dish. After several days they

attempt to pupate, but many of them die before completing the transformation. Even when they succeeded in pupating, the adults never matured from them. Evidently this is due to a lack of moisture, which seems to be a vital factor to all stages of development in this insect.

PUPARIUM.

In common with other fruit flies, this insect passes the pupal stage in the ground. The puparia occur naturally under the infested trees in the soil, for, as stated above, the maggots do not travel around, but go into the ground where they fall. The average depth of the puparia is 2 inches, although they vary anywhere from the surface to 3 inches deep, and sometimes occur also under rock and rubbish on the surface. The moisture in the earth seems to determine largely this point, for they go down until they can get into damp soil. Very rarely one is found inside the fruit either on the tree or on the ground.

The puparia (Pl. I, B) are of a stout, subcylindrical form with rounded ends and vary in length from 8.5 to 12 mm. The size is no indication of sex, for from 100 of the smallest ones obtainable about an equal number of males and females emerged. The color of the puparia varies all the way from a light ferruginous yellow to dark brown or almost black. This color in no way indicates their age, for some remain light colored throughout their existence.

The pupal stage was found to vary from 18 to 44 days in breeding out several hundred in all months of the year. Aside from the temperature changes the effect of the moisture is a very large factor in this regard. Under favorable conditions of moisture the largest number of the adults will emerge after 18 to 20 days in hot weather, but in winter this runs up between 30 and 40 days on the average. Hooker⁴ found it to last from 17 to 21 days in Porto Rico. Moisture, even more than heat, seems to be the determining factor. Lack of moisture will prolong very materially the pupal stage and if continued will prove fatal. On the other hand, excessive moisture will kill the puparia. The following data prove this point:

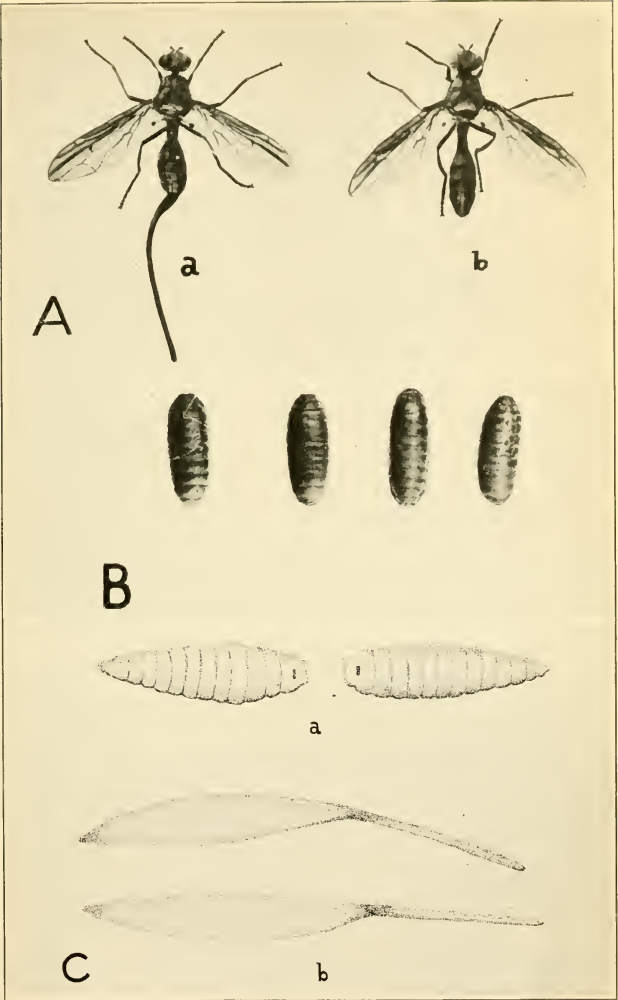
One hundred fresh puparia placed in soil in a jar and kept without any water being added. All died.

One hundred fresh puparia placed in soil in a jar and kept moderately moist; 80 adults emerged, 20 died.

One hundred fresh puparia placed in soil in a jar and kept wet every day. All died.

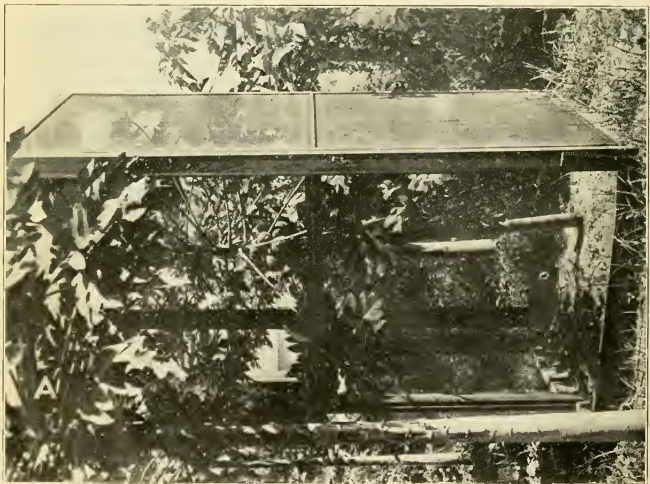
Even under the most favorable conditions of heat and moisture the puparia do not all mature, and 70 per cent is a very good average. Under natural conditions the average runs below that. Sev-

⁴ Hooker, C. W. Fruit flies. In Porto Rico Agr. Exp. Sta. Ann. Rpt. 1912, p. 36. 1913.



TOXOTRYPANA CURVICAUDA.

A, Adult flies: *a*, Female; *b*, male. $\times 2$. B, Puparia. $\times 1\frac{1}{2}$. C, *a*, Larvæ, $\times 2$; *b*, eggs, $\times 20$



TOXOTRYPANA CURVICAUDA.

At left, type of cage used for rearing papaya fruit flies in fruits on the tree. At right, papaya fruits after being stung, showing characteristic exudate of milky fluid caused by the females puncturing the skin. (Photo by G. F. Moznette.)

eral hundred puparia placed in jars, some of them reared from larvæ and others gathered in the soil under trees, gave results as shown in Table I.

TABLE I.—*Males and females of Torotrypana curvicauda maturing from puparia placed in jars.*

Number of pupæ.	Number of males.	Number of females.	Total emerged.	Total died.
870	279	281	560	310

Thus it is seen that only 64.3 per cent matured into adults, while 35.7 per cent died. Of the number maturing practically 50 per cent were males and 50 per cent females.

Practically all the adults emerge from the soil in early morning just before daylight. Very rarely will one emerge between sunrise and midnight. The adults often carry the pupal case to the surface of the ground before freeing themselves from it. Only a few minutes are then required for their complete development.

ADULT.⁵

The adult of this species (Pl. I, A) is a wasplike fly, very much resembling in coloration and general appearance the wasps of the genus *Polistes*. The body is yellow and brown, marked with black, and the females are made strikingly conspicuous by a long, curved ovipositor, even longer than the body itself. There is considerable variation in the size of the flies, but they average about 12 mm. in length. The ovipositor of the female varies from 10 to 14 mm. in length.

The flies exhibit a rather rapid flight and walk with a quick nervous motion. The females are not often seen on bright days but appear about the trees to lay their eggs in the late afternoon or evening. They show a negative reaction to sunlight and always seek the shady side of the tree or fruit. Although sometimes seen during the morning and noon hours, the greatest flight occurs about an hour before sunset. The males, however, are more active on bright days. Both sexes are easily disturbed when resting on the fruits.

The life of the adult flies is probably only a few days in length. They have been kept alive in captivity for 31 days when properly fed, although the average is very much less. The flies will eat any kind of sugar sirup and the pulp and juices of some fruits, but they never appear to be attracted by any food. Many will die without

⁵ For original description see Gerstaecker, A. Beschreibung einiger ausgezeichneten neuen Dipteren aus der familie Muscariae. In Ent. Zeitung Stettin, Jahrg. 21, No. 4/6, p. 194-195. 1860.

ever eating when food is placed at their disposal. Others will eat only when food is placed directly in front of them or when they happen to walk into it. When they have once tasted the sweets they will feed until the body is well distended. The best results were obtained by placing drops of brown-sugar sirup on the net or screen covering of the cages. In the large cages it was sprayed with an atomizer on the under side of the leaves of the tree. The flies have a liking for the pulp of ripe papayas and also eat bananas but will not eat the juice of oranges.

The following figures show the length of life of some of the flies:

Fifty-four flies confined without food after emerging lived from 1.5 to 5.5 days, with an average of 3.45 days.

Thirty-six flies given water only lived from 3 to 6 days with an average of 4.6 days.

Seventy-six flies fed on sugar sirup lived from 3 to 31 days with an average of 7.4 days.

Under natural conditions these figures probably do not vary much. Five to seven days represent an average life for the adult.

COPULATION.

The insects copulate usually on the leaves or fruits of the papayas, but can only rarely be observed. Copulation takes place during the daytime, for the male is more active then, as noted above. He seems to experience some difficulty in holding the female in position because of the long ovipositor. To accomplish his object, he alights on top of the female and, clasping her body with the first two pairs of legs, he draws the ovipositor back and up with the remaining pair. Then by practically standing on his head he is able to bring the tip of his abdomen in conjunction with the end of the ovipositor. They usually hold this position for several minutes or longer, one pair being observed to remain for nearly two hours. If disturbed the female will walk around the fruit or even fly to another tree, always carrying the male along in position. In captivity the flies very seldom copulate. This is true when confined in the large cages over the trees (Pl. II, at left) as well as in small cages or jars in the laboratory. Of several hundred adults bred out in jars and observed at all hours of day and night, only a very few ever made any attempts at copulation. These cases happened when the flies were 4 or 5 days old and had been fed on sugar sirup or fruit pulp. If given no food they soon die without mating.

OVIPOSITION.

Oviposition usually takes place in the evening, that being the time the adult females are most active. It has been observed occasionally, however, to take place at all other times of the day. The fruits selected by the females in which to lay their eggs are

usually medium or larger sized, if all sizes are present on the plant. They often begin work on a plant when the fruits have just set and are very small, and all sizes of fruits are subject to attack. They seem, however, to prefer the half-grown or larger fruits, perhaps due to a natural instinct, for if the eggs are deposited in a nearly mature fruit, the fruit may ripen and decay before the maggots have completed their growth. On the other hand, if placed in very small fruits the maggots will mature before the fruit has started to ripen, and they sometimes experience difficulty in escaping from green fruits. It has been said that the milky juice from the green fruits is fatal to the larvæ, but this has not been found to be true. In fact, maggots which had been rolled around in the juice from green fruits completed their development.

It is not often that an adult fly will oviposit in a fruit where eggs or maggots are already present, although in a few instances maggots of two distinct sizes were found. When the first ones to mature escape they cause the fruit to decay, so the younger ones may not be able to complete their development.

The adult fly alights on the fruit selected and usually walks around for a time with a nervous motion. When she has found a suitable place she forces her ovipositor through the skin and flesh of the fruit and deposits her eggs inside in the seed cavity. This is accomplished by raising the long ovipositor up in a curved position and placing the tip of it on the fruit near the end of the abdomen, then forcing it through the fruit. The position taken is much the same as that of the ichneumon flies in depositing their eggs.

The eggs are laid in clusters and ordinarily only one cluster will be placed in a single fruit, although occasionally two or three are found. The fly often stings a fruit several times, as many as 10 punctures being counted at times, but does not always deposit a cluster of eggs. Possibly she is not able to reach through the flesh of the fruit in all places and hence withdraws and seeks a new place. In fact, many fruits are stung several times and no eggs laid in them. This has often happened in the breeding cages where fruits supposedly containing eggs failed to develop any maggots. Also many fruits on the trees have been marked after being stung and no larvæ ever appeared in them. Usually about two minutes are required by the female to deposit the eggs, although instances have been noted where the ovipositor remained inserted for an hour or more. Occasionally a female will become trapped and die in the milky juice which wells up when the skin is punctured. This exudate coagulates and holds the fly if she does not soon escape. Whenever a fruit is stung the exudate produces a characteristic mark by running down the side of the fruit and also coagulating in a large

drop at the puncture. (Pl. II, at right.) It is possible thereby to determine easily the number and location of the punctures.

SEASONAL HISTORY AND OCCURRENCE.

The insects breed throughout the year in Florida and are present in all stages at any month of the year. They have, however, some seasonal preferences and occur in much larger numbers at some seasons than others. The time of greatest flight of the adults seems to be during March and April, while in late summer and fall there are very few of them in evidence. This is correlated largely with the growth of the host plants, which begin fruiting usually in the fall and continue through the winter and spring. Many of the plants die down or are cut out in the late spring and new ones set. The flies therefore appear on the new fruits in the fall and continue to breed in increasing numbers throughout the winter and spring. The wild papayas in the hammocks fruit at all seasons and always serve as hosts whether or not any of the cultivated sorts are available. The generations are by no means marked and vary in length from 40 days in summer to 70 or more in colder weather. In a year's time there are about six generations, although they overlap and are in no way distinct. Moisture in the soil is a very important regulating factor in the length of all stages, perhaps even more so than changes of temperature.

POWER OF FLIGHT.

The distance which the adults are able to travel is not very great, for they are not strong fliers. One planting of papayas under observation was placed 2 miles from where any other plants existed and remained free from infestation throughout the season, the adults apparently being unable to cover that distance. In most locations, however, there are wild papayas all through the surrounding hammocks, and these serve to harbor and spread them.

SUSCEPTIBILITY OF VARIETIES.

While no distinct varieties of the papaya (*Carica papaya*) are recognized, there are several types of the fruit grown in the State. Several have been introduced from foreign countries and crossed on existing types. Then there are the original wild plants which have been cross-pollinated on the cultivated plants through natural agencies. Through all this cross-pollination there result two rather distinct types of fruits, one the small, round, or oval type with rather thin skin and flesh and the other the large, oblong fruits which usually have thick flesh. One especially fine fruit of the latter type has been produced at the Plant Introduction Gardens at Miami, Fla.,

by Mr. Edward Simmonds, and is known as No. 28533. These oblong fruits are much more immune to the attacks of the flies, due largely to the fact that the female flies are unable to reach through the flesh of the fruit with their ovipositors and lay their eggs. In fact, in some places they were found practically free from infestation and are considered immune by the growers. An examination of about 300 fruits of all kinds on the Florida Keys, by A. L. Swanson, an inspector of the State Plant Board of Florida, showed 90 per cent of infestation in the small round fruits as compared to no infestation in the large oblong fruits. This latter fact has not held good, however, in investigations by the writer. Several hundred fruits examined both on the keys and in many places on the mainland showed about 88 per cent of the round or oval fruits infested and about 15 per cent of the oblong fruits infested. In wild fruits in the hammocks the infestation is close to 100 per cent. No papayas grown in the State are entirely immune from the attack of the flies.

ENEMIES.

Only two natural enemies have been noted on this insect, one the jumping spiders and the other the small red ants which sometimes prey upon the larvæ. The large black jumping spiders conceal themselves between the fruits on the tree and are then able to catch the flies when they alight near them. Doubtless they destroy many in this way. On a few occasions ants have been observed attacking the maggots in a fruit which had fallen to the ground. They enter through the exit hole of the first maggot to escape and can then destroy the remaining larvæ in the fruit. They represent a negligible factor, however, in the control of the pest.

Six hundred pupæ dug from the soil under the trees and bred out in jars failed to produce a single parasite. The insect is well protected from the attack of parasites through nearly the entire period of its life.

CONTROL MEASURES.

The most effective way of preventing injury from this pest is by bagging the trees or fruits. Either cheesecloth or mosquito netting can be tied over the trees or around the individual fruits, and the flies will not try to sting the fruits through it. However, this plan is hardly practicable on a large scale, since it requires considerable work and expense and, in many cases, changing the bags as the fruits grow larger.

The adults are readily killed by feeding them a poisoned sirup, the best results being obtained by using sodium arsenite or potassium arsenate dissolved in brown sugar sirup. When given this sirup the adult flies die very soon after feeding, and they eat it as readily

as the plain sirup. Very good killing results were also obtained by spraying this mixture with an atomizer on the under sides of the leaves of the trees in the large cages. Large numbers of flies were found dead on the ground within a couple of hours. These soluble poisons, however, burn the trees very severely and can not safely be used. Even at the rate of 1 pound to 50 gallons, which is as weak as can be effectively used, severe injury was noted. Insoluble arsenic compounds such as Paris green, arsenate of lead, arsenate of calcium, and arsenite of zinc do not damage the trees but are not effective. When the arsenic is mixed in the sirup the flies do not get enough to kill them.

The following plan if carried out thoroughly will very materially reduce the number of flies and make the growing of papayas practical and profitable: (1) Selection of good seed and production of fruits of oblong shape and thick flesh which will offer more or less immunity to attack; (2) conscientious destruction of the infested fruits on the trees early in the season and before the maggots escape into the ground; (3) destruction of all inferior plants and wild plants around the place which might serve to breed the pests.

If a planting is sufficiently isolated from other papayas the flies may be killed out by destroying all the plants in the spring, about April or May, and resetting new plants. These young plants will begin to fruit in the summer or early fall, but there will be a period of about 60 days when no fruits are present, which is long enough to starve out the flies. Along with this program should go the destruction of all wild plants in the hammocks for a radius of at least 2 miles. One large planting under observation was kept free from infestation for the entire winter by this method and a good crop of fruit obtained. The previous winter and spring the plants were badly infested, but the pests were entirely starved out during the summer. In most locations, however, a grower would not be sufficiently isolated to practice this method successfully unless the cooperation of his neighbors could be enlisted.

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PROFESSIONAL PAPER

JULY, 1922

BROAD-NOSED GRAIN WEEVIL.

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INTRODUCTION.

The broad-nosed grain weevil, *Caulophilus latinasus* Say, has received but little attention from economic entomologists, and practically nothing has been published on the biology of this insect. It is now widespread over Florida and has been reported from Georgia and South Carolina. It is not unlikely that it will gradually spread to other parts of the South and add to the already heavy damage caused by the rice weevil, *Sitophilus oryza* Linn.

The damage caused by the broad-nosed grain weevil is more than has been generally supposed. While more often found infesting stored corn and chick peas, it commonly attacks a variety of seeds and cereals. Infested seeds are quickly reduced to a powdery mass by the combined efforts of the grubs and adult weevils.

It is interesting to note that whole grain or seed of a medium degree of hardness is entirely immune from the attack of this weevil. The writer has many times confined weevils with whole grain and chick peas, with the result that invariably the weevils died from starvation without being able to penetrate the grain.

The broad-nosed grain weevil, however, is often associated with the common rice weevil, *Sitophilus oryza*, and the attack of the common rice weevil makes it a simple matter for its weaker associate to reach the softer portions of the grain. Cracked, damaged, or soft seed is quickly infested by the broad-nosed grain weevil.

The following notes on the life history and habits of this weevil were made at Orlando, Fla., during 1919, 1920, and a part of 1921.

ORIGIN AND ECONOMIC HISTORY.

Caulophilus latinasus was described in the year 1831 by Thomas Say (13: 1831, p. 30; 1859, p. 299)¹ from specimens taken in Florida. It is thought to be native to the American continent and is not as yet very widely distributed.

In 1878 Schwarz (14, p. 468) recorded it from Florida as "rare, beaten from dead twigs." Ten years later Riley and Howard (11, p. 198) stated that the genus lived under the bark of dead and decaying wood or bored into decaying wood of deciduous or coniferous trees. In 1894 Townsend² reported it as occurring in a can of ginger. Two years later Chittenden (3, p. 29-30) reported it for the first time as attacking stored grain, having found it in a shipment of corn and chick peas obtained from the Mexican exhibit at the Atlanta Exposition. In 1897 (4, p. 30-31) and 1911 (5) Chittenden published short accounts concerning the occurrence of this weevil in the United States, its synonymy, its reported distribution, the damage caused by it, etc., and also included a list of references to this species in literature.

Since then it has been reported by the following writers as attacking seeds of the avocado in Florida: Schwarz (1, p. 183), Sasser (12, p. 4-5), Blatchley and Leng (2, p. 535), Pierce (8, p. 30, pl. 49), Popenoe (9, p. 6) (10, p. 34-35, pl. 40), Hoyt (6), and Moznette (7). It was also found by inspectors of the Federal Horticultural Board infesting roots of dasheen in storage at Brooksville, Fla.

PRESENT KNOWN DISTRIBUTION.

Caulophilus latinasus is now widespread over Florida and has been reported from South Carolina and Georgia. So far as can be determined, it has not become permanently established in either of the two latter States. It is abundant within a few miles of the boundary between Florida and Georgia, however, and may be expected to invade the southern portion of Georgia.

It is known to occur in Jamaica, Cuba, Porto Rico, Mexico, Guatemala, and Madeira, and is doubtless common throughout the islands of the West Indies and in the countries of Central and South America.

FOOD.

Caulophilus latinasus is known to breed in corn, chick peas, millets, acorns, and seed of the avocado and has occasionally been found breeding in the roots of the dasheen and in sweet potatoes.

In addition, the adult weevils feed readily on wheat, barley, wheat flour, ginger, and macaroni. The writer has occasionally found them feeding on fresh fruits, and E. R. Sasser, of the Federal Horticultural Board, states that the board has observed injury to chayotes by this weevil.

¹ Reference is made by number (italic) to "Literature cited," p. 10.

² TOWNSEND, C. H. T. Institute of Jamaica, Notes from the Museum, No. 78, 1894. (Hectographed.)

LIFE HISTORY (PL. I).³

The adults of the broad-nosed grain weevil possess functional wings, and although not great fliers they are capable of making short flights in search of food. They fly to the cornfields in the summer, feed on the grain, and deposit eggs in it before it becomes fully hardened.

The damaged and exposed ears of corn are the ones that are attacked by the weevils, those ears that have a well-developed and tightly fitting shuck being entirely immune from attack.

After the grain is harvested and placed in storage the work of destruction continues. The kernels infested in the field are completely destroyed, and the multiplying weevils attack cracked and broken kernels and grain that is softened by excess moisture or is damaged by the depredations of other grain pests.

OVIPOSITION.

Under favorable conditions oviposition occurs more frequently during the hours of the morning; eggs are laid, however, at all times of the day.

The female weevil excavates the egg cavity in a manner very similar to that of *Sitophilus oryza*. The weevil places herself in the desired position. The sharp hook or claw on the end of the tibia of each leg is dug into the surface of the kernel, the four legs thus forming pivots on which the body oscillates. This oscillating movement of the body, together with a turning movement of the head, imparts to the proboscis a combined up-and-down and rotary motion. The position of the legs is not changed, as a rule, until the excavation is completed, and the proboscis or beak is seldom withdrawn during this time. Work on the cavity continues until its depth approximates the length of the beak from the tip to the eyes. The sides are then smoothed off.

After the completion of the cavity the weevil reverses her position and places the tip of her abdomen over the mouth of the egg cavity. After a period of from two to three minutes the egg is ejected from the ovipositor into the cavity, followed by a liquid secretion that forms a cap and cements the egg into place. This secretion quickly hardens. Immediately after the egg is deposited the weevil turns about and tamps down the edges of the egg cap with her beak, picking up small pieces of the borings from the excavation and tamping in around the edges.

The egg cap is transparent, and the outer surface is invariably exactly level with the surrounding surface of the corn. After the young larva has emerged from the egg and the egg cavity is filled with larval borings it is often difficult to detect the original position of the egg.

³ In breeding experiments from which the life-history data were taken corn was used as the host seed.

WHERE THE EGGS ARE LAID.

In broken or damaged corn the eggs usually are laid either in the germ or in the soft starch of the endosperm, and very rarely in the harder horny part of the kernels. In the case of undamaged kernels eggs are laid only if the corn is very soft, as ordinarily the seed coat is too tough for the weevil to penetrate.

OVIPOSITION PERIOD AND NUMBER OF EGGS LAID.

The preoviposition period of the broad-nosed grain weevil is apparently a little longer than that of the other grain weevils. The shortest period observed was nine days; however, it was not uncommon for a period of from one to two months to elapse after emergence before the first egg was laid.

The oviposition period, once started, extends over most of the remainder of the life of the weevil. The longest oviposition period observed was 176 days; the average was somewhat less, approximately 123 days.

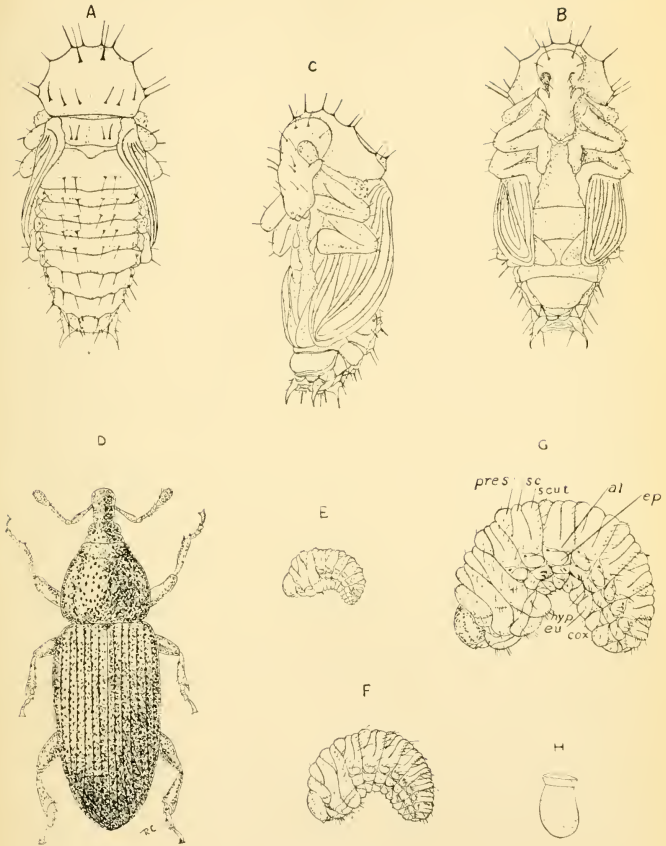
The number of eggs laid by the female of this species is not exceptionally great. The largest number laid by a single female under observation was 229. These were laid over a period of 124 days—August 13, 1919, to December 14, 1919, an average of almost 2 a day. As shown in Table 1, the average number laid is about 136. Table 1 contains data concerning the preoviposition period, the oviposition period, the number of eggs laid, and the length of life of 11 representative individual weevils.

TABLE 1.—Oviposition data for *Caulophilus latinasus*.

Weevil No.	Date weevil emerged.	Length of pre-oviposition period.	Date first egg was laid.	Date last egg was laid.	Length of oviposition period.	Number of eggs laid.	Date of death.	Length of life.
		<i>Days.</i>			<i>Days.</i>			<i>Days.</i>
1.....	June 28, 1919	16	July 14, 1919	Dec. 15, 1919	155	196	Dec. 20, 1919	176
2.....	do.....	46	Aug. 13, 1919	Dec. 14, 1919	124	229	Dec. 22, 1919	178
3.....	Sept. 11, 1919	13	Sept. 24, 1919	Dec. 15, 1919	83	152	do.....	103
4.....	Feb. 25, 1920	31	Mar. 27, 1920	Aug. 4, 1920	131	65	Aug. 13, 1920	171
5.....	May 6, 1920	57	July 2, 1920	Oct. 6, 1920	97	156	Oct. 17, 1920	165
6.....	Aug. 1, 1920	9	Aug. 10, 1920	Jan. 24, 1921	168	182	Feb. 1, 1921	185
7.....	do.....	9	do.....	Oct. 27, 1920	79	85	Nov. 4, 1920	96
8.....	Aug. 7, 1920	12	Aug. 19, 1920	Oct. 26, 1920	69	68	Nov. 2, 1920	88
9.....	do.....	13	Aug. 20, 1920	Feb. 11, 1921	176	160	Feb. 16, 1921	194
10.....	Aug. 9, 1920	22	Aug. 31, 1920	Feb. 9, 1921	163	127	do.....	192
11.....	Oct. 12, 1920	12	Oct. 24, 1920	Feb. 11, 1921	111	75	Feb. 19, 1921	131
Average.....		22			123	136		152

RATE OF OVIPOSITION.

Oviposition continues throughout the year in a fairly uniform manner. In the summer months the rate of oviposition averages about two eggs a day, while in winter the rate drops to about one per day. It is not uncommon for three and four eggs to be laid per day during the summer, and in the colder portions of winter oviposition may cease entirely for a day or two. The greatest number laid by one individual in 24 hours was six. This occurred but once. Table 2 contains data concerning the rate of oviposition at various times of the year.



CAULOPHILUS LATINASUS.

A, Pupa, dorsal view; B, pupa, ventral view; C, pupa, lateral view; D, adult; E, first-stage larva; F, second-stage larva; G, mature larva; H, egg.
Key to larval parts: *al*, Alar area; *cox*, coxal lobe; *ep*, epipleurum; *eu*, eusternum; *hyp*, hypopleurum; *pres*, praescutum; *sc*, scutum; *scut*, seutellum.

TABLE 2.—Rate of oviposition of *Caulophilus latinasus*.¹

Date.	Temperature.			Number of eggs laid by weevil No.—							Date.	Temperature.			Number of eggs laid by weevil No.—						
	Max.	Min.	Mean.	1	2	3	4	5	6	7		Max.	Min.	Mean.	1	2	3	4	5	6	7
1920.	° F.	° F.	° F.								1920.	° F.	° F.	° F.							
Aug. 10	94	70	82	1	1	...	...	...	...	...	Nov. 29	77	48	62.5	1	...	...	1	1	1	1
12	95	70	82.5	1	0	(?)	...	...	...	...	1	71	58	64.5	1	...	...	3	1	1	1
19	95	69	82	2	1	1	(?)	...	...	...	2	70	41	55.5	0	...	...	0	0	1	0
20	95	69	82	2	1	1	1	...	...	...	7	78	59	68.5	1	...	...	2	2	1	1
26	97	70	83.5	1	1	4	1	...	...	...	8	72	58	65	2	...	...	2	2	1	2
27	94	69	81.5	1	2	3	1	...	...	...	13	84	55	69.5	3	...	...	1	3	2	1
Sept. 4	90	69	79.5	1	2	1	1	(?)	...	...	14	75	67	71	2	...	...	1	2	2	0
5	92	70	81	2	2	2	2	1	...	...	18	70	36	53	0	...	...	0	0	0	0
11	96	72	84	4	1	0	2	1	...	...	19	75	37	56	0	...	...	0	0	0	0
12	98	69	83.5	2	2	2	1	2	...	...	26	78	44	61	1	...	...	1	1	1	1
17	89	67	78	2	1	1	1	1	...	...	27	84	68	76	1	...	...	1	3	4	2
18	92	68	80	3	3	1	1	2	...	...	1921.										
24	84	70	77	4	2	1	2	0	...	...	Jan. 1	84	44	64	1	...	...	1	2	2	2
25	89	70	79.5	4	2	1	2	2	...	...	2	79	62	70.5	1	...	...	2	2	1	1
Oct. 1	75	46	60.5	2	1	1	1	1	...	...	7	74	45	59.5	1	...	...	0	1	0	1
2	82	48	65	1	2	0	1	0	...	...	8	79	51	65	0	...	...	0	0	1	0
8	80	50	65	0	0	1	0	0	...	...	13	78	48	63	1	...	...	0	1	1	0
9	84	52	68	0	0	1	0	0	...	...	14	79	61	70	0	...	...	0	1	1	1
15	88	62	75	0	0	1	0	0	...	...	18	79	46	62.5	0	...	...	2	1	0	1
16	88	60	74	0	0	1	0	0	...	...	19	73	53	63	1	...	...	0	1	0	1
26	87	64	75.5	2	2	1	2	1	1	1	23	83	50	66.5	1	...	...	1	1	1	1
27	88	66	77	2	2	(?)	2	2	1	1	24	81	49	65	1	...	...	0	1	1	1
Nov. 1	84	59	71.5	1	(*)	...	1	0	0	0	Feb. 1	84	50	67	(?)	...	...	0	1	0	0
2	86	57	71.5	2	...	...	2	0	0	0	2	82	44	63	...	...	...	0	0	0	1
7	85	60	72.5	1	...	...	2	0	0	1	7	84	58	71	...	...	...	1	2	1	1
8	86	60	73	2	...	...	2	0	0	1	8	84	52	68	...	...	...	1	2	1	2
14	78	57	67.5	0	...	...	1	2	0	1	13	74	38	56	...	...	...	0	0	0	1
15	75	63	53.5	0	...	...	0	0	0	0	14	74	40	57	...	...	...	0	0	0	0
20	81	52	66.5	1	...	...	1	2	0	0	20	...	...	...	...	...	...	(*)	(*)	(?)	2
21	83	54	68.5	0	...	...	1	2	1	1	21	80	52	66	...	...	...	...	...	...	1
28	76	58	67	0	...	...	1	2	1	1	...	...	...	...	...	...	...	...	...	...	(10)

¹ The mean temperature of the crib in which these records were made is about 3° to 4° F. higher than the outdoor temperature quoted in this table.

² Emerged Aug. 7, 1920.

⁵ Died Nov. 2, 1920.

⁸ Died Feb. 16, 1921.

³ Emerged Aug. 9, 1920.

⁶ Died Nov. 4, 1920.

⁹ Died Feb. 19, 1921.

⁴ Emerged Oct. 12, 1920.

⁷ Died Feb. 1, 1920.

¹⁰ Still alive.

EGG STAGE.

During the summer months, with the temperature ranging from 65° to 99° F., with a mean of 81°, the egg hatches in four days. As the weather gets colder the incubation period gradually lengthens until, in the coldest winter months, with the temperature ranging from 34° to 88° F., with a mean of 62°, from 10 to 14 days is the normal length of the period.

LARVAL PERIOD.

When the egg is placed in the germ or in the starch of the kernel the young grub, breaking through the bottom of the shell, finds a plentiful supply of food. Development of the grub is most rapid when it is located in the germ. Progress is a little slower in the soft starch, while development in the tough horny endosperm is very slow and the larval period is greatly prolonged.

NUMBER OF LARVAL STAGES.

There are three larval stages. The first two are about equal in length, while the third is slightly longer. Table 3 gives data showing the variation in the length of these stages at different times of the year.

TABLE 3.—*Life history data of Caulophilus latinasus.*

No.	Date egg was laid.	Date egg hatched.	Length of egg stage.	Date of first molt.	Length of first larval stage.	Date of second molt.	Length of second larval stage.	Prepupal form.	Length of third larval stage.	Date pupated.	Length of prepupal stage.	Adult emerged.	Length of pupal stage.	Period from egg to adult.	Temperature for period of development.		
															Maxi-mum.	Mini-mum.	Mean.
1	Aug. 1	Aug. 5	Days. 4	Aug. 11	Days. 6	Aug. 17	Days. 6	Aug. 22	Days. 5	Aug. 23	Days. 1	Aug. 28	Days. 5	Days. 27	° F. 94	° F. 71	° F. 82.5
2	Aug. 8	Aug. 12	4	Aug. 18	4	Aug. 22	4	Aug. 30	8	Aug. 31	1	Sept. 5	5	28	94	69	81.5
3	Aug. 10	Aug. 14	4	Aug. 19	3	Aug. 22	3	Sept. 29	7	Sept. 30	1	Sept. 4	5	25	94	69	81.5
4	Aug. 11	Aug. 15	4	Aug. 20	6	Aug. 26	6	Sept. 1	6	Sept. 2	1	Sept. 7	5	27	94	69	81.5
5	Aug. 13	Aug. 17	4	Aug. 22	5	Aug. 27	5	Sept. 1	5	Sept. 2	1	Sept. 7	5	25	94	69	81.5
6	Mar. 25	Mar. 30	5	Apr. 7	6	Apr. 13	6	Apr. 26	13	Apr. 27	1	May 2	5	38	86	61	73.5
7	Mar. 28	Apr. 2	5	Apr. 10	8	Apr. 17	7	Apr. 27	10	Apr. 28	1	May 4	6	37	86	61	73.5
8	June 30	July 6	6	July 12	6	July 17	5	July 31	14	Aug. 1	1	Aug. 6	5	37	92.5	70	81
9	July 1	July 5	4	July 12	7	July 17	5	July 23	6	July 24	1	Aug. 2	5	28	93	70	81.5
10	July 1	July 5	4	July 12	7	July 17	4	Aug. 27	11	Aug. 28	1	Aug. 2	5	32	93	70	81.5
11	July 10	July 14	4	July 16	6	July 22	4	Aug. 8	11	Aug. 9	1	Aug. 14	5	35	92	70	81
12	July 11	July 15	4	July 17	5	July 22	5	Aug. 3	8	Aug. 4	1	Aug. 14	5	35	92	70	81
13	Nov. 11	Nov. 15	7	Dec. 1	14	Dec. 19	17	Dec. 30	11	Jan. 1	2	Jan. 14	13	64	76	51	63.5
14	Nov. 16	Nov. 20	8	Dec. 5	15	Dec. 20	15	Jan. 5	16	Jan. 7	2	Jan. 20	13	63	76	49	62.5
15	Dec. 2	Dec. 6	10	Jan. 12	10	Jan. 27	15	Jan. 11	15	Jan. 13	2	Feb. 9	27	79	76	50	63
16	Dec. 6	Dec. 10	14	Jan. 3	13	Jan. 13	10	Feb. 3	21	Feb. 5	2	Feb. 20	15	76	76	50	62.5
17	Dec. 13	Dec. 17	14	Jan. 10	14	Jan. 26	16	Feb. 14	19	Feb. 15	1	Mar. 26	11	75	75	50	63.5
18	Dec. 22	Jan. 2	11	Jan. 14	12	Jan. 26	13	Feb. 11	15	Feb. 12	1	Mar. 24	12	64	76	51	63.5
19	Jan. 4	Jan. 14	10	Jan. 27	13	Feb. 8	12	Feb. 22	14	Feb. 24	2	Mar. 8	12	63	76	51	63.5

LARVAL HABITS.

The larva or grub bores straight down into the grain at first and is rarely found near the surface. It tunnels around rather aimlessly, filling up the passageway behind it with frass and borings. It usually remains in the soft parts of the grain.

PREPUPAL STAGE.

When fully grown the larva prepares for the change to the pupa or resting stage. It uses the end of its burrow for a pupal chamber, packing the frass and borings at the ends into a compact mass.

The larva lengthens out and becomes sluggish, assuming the prepupal form. This stage lasts for one day in warm weather and two days in winter.

PUPAL STAGE.

The pupal stage lasts for a period of five days during warm weather when the temperature ranges from 65° to 99° F., with a mean of about 81°. As with the other stages, cold weather has the effect of lengthening the period. Table 3 contains data showing the varying length of this stage at different times of the year.

NUMBER OF MALES AND FEMALES.

Of several hundred weevils reared in the laboratory and of large numbers collected in the field, the males and females were about equal in numbers. The males and females closely resemble each other in outward appearance and can not be differentiated without the aid of a magnifying glass.

As with many other weevils the beak of the female differs slightly from that of the male and affords a ready means of distinguishing between the two sexes. The beak or proboscis of the female is approximately equal in width for its entire length and is longer and more slender than that of the male. The beak of the male is slightly enlarged at the tip and narrows gradually toward the base.

COPULATION.

Copulation occurs within a few days after emergence and is repeated at intervals. It occurs chiefly at night. These weevils are rarely to be seen in copula during the day.

Unfertilized females have been observed to lay eggs but rarely. None of these eggs have been found to hatch, so it is doubtful whether unfertilized females are capable of laying fertile eggs.

LIFE CYCLE.

The period from egg to adult during warm weather averages about 30 days, which with an average preoviposition period of 22 days gives

an average life cycle of 52 days. This is 18 days longer than the shortest record obtained and considerably shorter than the life cycle during the winter months.

LONGEVITY.

The average length of life of the adult weevil is about 152 days when reared in captivity. Of fertilized females one lived for 209 days while two unfertilized females lived for 240 and 244 days, respectively.

When deprived of food these weevils are capable of living for extended periods if the temperature is not too high. Fifty weevils were placed without food in a chamber with a constant temperature of 60° F. The majority lived for a period of 55 days, while a few survived for 90 days and one for 96 days. During normally warm weather these weevils will live for from 5 to 12 days without food.

PARASITES.

The larvæ of this weevil are attacked by three hymenopterous parasites, *Cercocephala elegans* Westwood, *Aplastomorpha vandinei* Tucker, and *Zatropis* sp.

Larvæ, pupæ, and eggs are all attacked by a predacious mite, *Pediculoides ventricosus* Newport.

CONTROL MEASURES.

This weevil may be effectively controlled by the standard remedies advocated for the control of insect pests of stored grain.

TECHNICAL DESCRIPTION OF IMMATURE STAGES.

EGG.

Egg opaque, shiny white, bottom broadly rounded, top flattened and fitting into a translucent cap. Length, without cap, 0.45 to 0.47 mm.; width, 0.27 to 0.32 mm.

LARVA.

Mature larva 2 to 2.5 mm. in length, a white, footless, fleshy grub, with body curved and wrinkled. Head light brown or straw color, the anterior margin and mandibles a darker brown. Head about as broad as long, almost circular in form. Epicranial and frontal sutures distinct and light in color. There are also two oblique, longitudinal, light stripes rising from the frontal sutures and coalescing with the epicranial suture near the base of the head. Frons subtriangular, with a distinct dark median line running from posterior angle to middle, and indicating carina. Frons provided with four pairs of large setæ, sutural margins each bearing one seta. Epicranial lobes bearing the following setæ: One close to posterior angle of frons and located in the oblique, longitudinal stripe rising from the frontal suture, one small seta posterior to this and near occiput, two anterior to it on disk of epicranium, two opposite middle of frons, one opposite middle of mandible, one opposite hypostomal angle of mandible and one on hypostoma near base of mandible. Epistoma represented by thickened anterior margin of the front. Pleurostoma represented by somewhat darker declivous

area surrounding the mandibular foramen. Mandibles stout, triangular, with the apex produced into an acute apical tooth. Inner edge toward apex provided with a subapical tooth and a small medial tooth, no molar structure. Dorsal area of each mandible armed with a pair of stout bristles set close together. Eye represented by a well-defined black spot beneath the exoskeleton. Clypeus broad at base, sides narrowing towards apical angles; distinctly broader but not as long as labrum. Epistomal margin provided with two fine hairs on each side. Labrum about as broad as long, rounded in front, provided with three pairs of large setæ and five pairs of short, thickened, marginal setæ.

Maxillæ terminated by a 2-jointed palpus and setose maxillary lobe. Maxillæ each provided with four setæ as follows: One on first segment of palpus, two on vaginant membrane between palpus and palpifer, and one stouter and larger midway between palpus and cardo. The stipes labii enforced posteriorly by a median triangular chitinization bear 2-jointed palpi and a single pair of setæ. Ligula bearing four small setæ. Mentum and submentum fused and bearing three large setæ on each side. Pronotum simple and undivided. Præscutal and scuto-scutellar areas roughly indicated by rows of setæ. Mesothoracic and metathoracic segments divided above into two areas representing præscutum and scuto-scutellum; below and adjacent to epipleurum is the alar area. Below ventro-lateral suture are a well-defined hypopleurum, coxal lobe, and eusternum. The thoracic spiracle, located on the pre-epipleural lobe of the mesothorax, is bifore, with the fingerlike air tubes pointing dorsad, and is somewhat larger than the abdominal spiracles. Ten abdominal segments, ninth small, tenth reduced. Each tergum of first eight abdominal segments divided above into three distinct areas—præscutum, scutum, and scutellum. Below and adjacent to epipleurum is the alar area. Below ventro-lateral suture are a well-defined hypopleurum, coxal lobe, and eusternum. Abdominal segments provided with setæ as follows: Two on præscutum, five on scutellum, two on alar area, two on epipleurum, one on coxal lobe, and two on eusternum. Each of the first eight abdominal segments bears a bifore spiracle, that of the eighth being slightly larger than the rest.

Stage.	Width of larval head.
1.....	0.22 to 0.23 mm.
2.....	.33 to .38 mm.
3.....	.53 to .57 mm.

PUPA.

Pupa white when first transformed. Length, 2.8 to 3 mm.; width, about 1.3 mm. Tips of elytra attaining the sixth abdominal segment, tips of metathoracic tarsi not extending beyond wing tips. Head rounded, beak short and broad. Head provided with two prominent spines toward the vertex, two smaller ones on sides above eyes, a spine on each side of front between eyes, two pairs on beak between frontal ones and base of antennæ, two pairs on beak between base of antennæ and tip of beak, and four pairs of small setæ on tip of beak. Prothorax provided with two pairs of antero-marginal setigerous tubercles, one pair of antero-lateral, two pairs of postero-lateral, and four pairs of dorsal setigerous tubercles. Mesonotum and metanotum each provided with two pairs of spines. Abdomen with eight distinct dorsal tergites; dorsal area of each armed with two pairs of large spines; lateral area of each tergite armed with a spine at base of which is a small seta. Epipleural lobes each obscurely armed with one or two minute setæ. Ninth segment armed as usual with two prominent pleural spines.

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BULLETIN No. 1088



Washington, D. C.

PROFESSIONAL PAPER

July, 1922

ZYGOTHRIA NIDICOLA, AN IMPORTANT PARASITE OF THE BROWN-TAIL MOTH.

By C. F. W. MUESEBECK,¹ *Scientific Assistant, Gipsy Moth and Brown-tail Moth Investigations, Bureau of Entomology.*

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INTRODUCTION.

One of the most effective factors in the control of the brown-tail moth (*Euproctis chrysorrhoea* L.) in the United States is the introduced tachinid fly *Zygobothria nidicola* Townsend. Strangely enough this European parasite had not been described at the time it was first obtained in this country. The first adults were reared at the Gipsy Moth Laboratory, then located at North Saugus, Mass., in the summer of 1906, from brown-tail moth caterpillars that had been received from Europe during the preceding winter. The specimens were referred to Mr. C. H. T. Townsend, of the Bureau of Entomology, United States Department of Agriculture, for identification. After some correspondence with European authorities, to whom also specimens were submitted for examination, Mr. Townsend concluded that the species was new, and subsequently described it under the name *Zygobothria nidicola*.²

Much difficulty was experienced in rearing adults of the parasite for colonization from imported brown-tail moth larvæ. This was due to the great mortality among the caterpillars, particularly from

¹ Special acknowledgments are due Mr. A. F. Burgess, in charge of Gipsy Moth and Brown-tail Moth Investigations, for helpful criticism of this bulletin, and Messrs. S. S. Crossman and R. T. Webber, of the Gipsy Moth Laboratory, Melrose Highlands, Mass., for many suggestions during the prosecution of the work.

² TOWNSEND, CHARLES H. T. THE TAXONOMY OF THE MUSCOIDEAN FLIES, INCLUDING DESCRIPTIONS OF NEW GENERA AND SPECIES. In Smithsonian Miscellaneous Collections, v. 51, p. 99-101. 1908.

disease, before the parasites completed their development. Despite the discouraging results of the breeding work, however, *Z. nidicola* became established, and by 1910 had definitely taken its place in our fauna. The trying experiences of the laboratory force, in their attempts to establish this parasite, are interestingly recounted by Howard and Fiske.³

DISTRIBUTION IN THE UNITED STATES.

Because it evidently has no hosts other than the brown-tail moth the parasite must necessarily remain within the area over which this insect occurs; but within these limits it appears to be widely distributed, although it is relatively less abundant in the sections where very low temperatures are reached during the winter. It has been recovered from Rhode Island to northeastern Maine—very abundantly in the former region, sparingly in the latter. This wide dissemination, within some seven or eight years, is very largely the result of natural spread, since there has been little artificial colonization of this species.

LIFE CYCLE OF THE BROWN-TAIL MOTH.

Before taking up in detail the biology of the parasite it will be well to review briefly the life cycle of its host. During July the female brown-tail moth deposits her eggs on the underside of a leaf of one of the favored food plants—apple, pear, oak, or wild cherry. Usually the terminal leaves of the uppermost shoots of the tree are selected for oviposition. The eggs hatch in about three weeks and the small caterpillars feed on the epidermis of the leaves, preferring the terminal ones, which they gradually tie together with a large amount of silk. This process is slow, but ultimately a firm, tough web, about 3 or 4 inches long, is formed. By this time the majority of the slowly growing larvæ are in the third stage and are ready for hibernation. In the spring feeding begins as soon as the buds open, and continues until the middle of June, when cocoons are formed and pupation occurs. Moths issue during the first half of July, and, after a few days, lay their eggs. There is only one generation annually.

LIFE HISTORY AND BIOLOGY OF THE PARASITE.

EMERGENCE AND LONGEVITY OF THE ADULTS.

Adults of *Z. nidicola* appear during the latter half of July. They are very sturdy flies (Fig. 1) and endure unfavorable conditions well, normally living for a period of at least several weeks. Some

³ HOWARD, L. O., and FISKE, W. F. THE IMPORTATION INTO THE UNITED STATES OF THE PARASITES OF THE GIPSY MOTH AND THE BROWN-TAIL MOTH. U. S. Dept. Agr., Bur. Ent. Bul. 91, p. 289-295. 1911.

specific data with regard to the length of life were obtained from laboratory experiments in which various types of cages were used. These consisted of: (1) Plain glass cylinders, measuring 50 by 200 mm., closed at one end; (2) ordinary shell vials, 22 by 100 mm.; and (3) a wooden cage, which had been successfully used by Mr. J. J. Culver in his life-history studies upon *Compsilura concinnata* Meigen, a tachinid parasite of both the brown-tail moth and the gipsy moth.

The glass cylinders were rather satisfactory for two to five flies each, when a bit of crunched crêpe paper was placed inside to afford the flies a good footing, but it was necessary to change the cylinders



FIG. 1.—Adult male of *Zygobothria nidicola*.

every few days because they quickly became dirty and sticky, and this involved a good deal of work. This objection applied to the shell vials as well, which in addition were found to be too small even for individual flies. The wooden cage was by far the most satisfactory. It measures about 12 inches square and 4 inches high, and is fitted with a cloth bottom to facilitate cleaning after each experiment; the top is a piece of window glass of the proper size. One-inch holes bored in the sides of the box and covered with fine wire gauze insure good ventilation. Another opening of the same size is fitted with a cork and is used for introducing the flies. Feeding is facilitated by the use of a larger opening, about 2 inches in diameter, which can be closed with a wooden stopper. After the flies were placed in this cage they were left entirely alone save for the feeding, which

was done on alternate days. This process merely involved slipping a narrow strip of blotting paper, which had been soaked in a mixture of honey and water, into the cage, and removing the old strip which had been placed there two days before.

Only a small proportion of the flies confined in the glass cylinders or shell vials lived from 25 to 28 days, and then only upon receiving particularly good care; those in the wooden cages which were given comparatively little attention lived five weeks and more. Two males and one female, which were confined in one of these wooden cages, were apparently in as good condition at the end of a 40-day period, when the experiment was discontinued, as when first placed in the box; several larger lots did about as well. The data obtained certainly demonstrate the ability of *Z. nidicola* to live a long time; and since even at best the artificial methods of the laboratory probably can not provide the equivalent of natural conditions, it seems safe to assume that in nature the average life of *Z. nidicola* is at least 25 to 30 days.

EMBRYONIC DEVELOPMENT.

Mating takes place within a few hours after emergence, sometimes even before either fly has fed. Following impregnation the uterus of the female fly gradually becomes much elongated and coiled, ultimately attaining a length of 7.5 to 8 mm., which is about the length of the entire insect. This enlargement results from the stretching of the walls of the organ as the enormous numbers of fertilized eggs pass into it and arrange themselves in more or less regular spiral layers. Embryonic development requires from seven to eight days. At the end of this period the lower part of the uterus contains a considerable number of maggots, each still enclosed within its egg-chorion. From 12 to 16 days after impregnation two-thirds of the 600 or more eggs in the uterus have fully formed first-stage maggots within them, if the fly has not been ovipositing as rapidly as they have developed.

OVIPOSITION.

The female fly prefers as its victims brown-tail moth caterpillars that are from several days to two weeks old, but even those just out of the egg are often successfully parasitized. Most of the oviposition by this species takes place during the first three weeks of August, in normal seasons.

Oviposition was readily obtained in the laboratory by confining a fertilized female fly in a shell vial with a few brown-tail moth larvæ that had been placed upon a small piece of cherry leaf. Having found the caterpillars, the parasite manifested much interest, passing slowly from one larva to another and inspecting each minutely. Then, with her face but a few millimeters from one of

the caterpillars, she slowly and deliberately pushed her abdomen downward and forward until the ovipositor plates were even with her face. With a quick movement the ovipositor was then pushed beneath the larva, and an egg with a first-stage maggot within it was deposited. The egg is almost invariably placed on the venter of the host, and usually occupies a transverse position between two pairs of true legs, or, less frequently, between two pairs of prolegs. Occasionally an egg is placed on the dorsum by accident, but in such cases the parasitic maggot is unable to enter its host—at least this was true of instances under observation in the laboratory. The explanation probably is to be found in the thicker skin of the dorsum, which is not so easily pierced by the small maggot.

Although only one parasite can complete its development in one host larva, the fly uses no discrimination when depositing her eggs; she places eggs as readily upon larvæ already having eggs upon them as upon those not yet attacked. From five to eight eggs have been found on one caterpillar. That this takes place under field conditions as well as in the laboratory has been disclosed by dissections; from 6 to 10 first-stage maggots of the parasite have been not uncommonly dissected from single field-collected brown-tail moth caterpillars.

EGG.

As deposited, the egg measures from 0.42 to 0.45 mm. in length by 0.11 to 0.12 mm. in width; the maggot within is 0.33 to 0.35 mm. long and 0.08 to 0.09 mm. broad. In form the egg is elongate-oval, somewhat narrowed at the posterior end, and concave on the lower side; in color it is whitish. The thin and delicate chorion is transparent. When viewed from above the egg appears opaque; this is due to what seems to be a special layer of protecting tissue just inside the chorion; it is limited to the posterior three-fourths of the egg, and occurs only above the maggot. It is peculiarly reticulated, being marked off into very slender hexagons, the outermost of which are incomplete. Its position suggests its function to be that of affording protection to the young maggot before the latter succeeds in boring into its host.

ENTRANCE OF MAGGOT INTO HOST.

Having been placed upon its host the parasitic maggot begins to cut through the thin egg chorion that confines it, and as soon as this is done it bores into the caterpillar. The posterior end of the parasite remains inside the eggshell until the opening into the host has been made; when this has been accomplished it requires but a fraction of a second for the maggot to pull its whole body into the caterpillar. In one case under observation the entire process of cutting through the egg chorion and the host skin and entering the

brown-tail moth caterpillar was completed within 10 minutes after the egg had been deposited. From many observations it appears that normally 20 to 30 minutes elapse between oviposition and the entrance of the parasitic larva into its host. Often the caterpillar makes vigorous attempts to destroy the maggot before the latter has made its way inside, and occasionally these efforts are successful, particularly if the egg of the parasite was deposited near the posterior end of the host. In this case the brown-tail moth

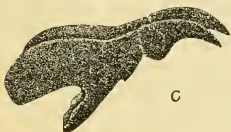
larva, by doubling its body, can reach the parasite and crush it with its mandibles.



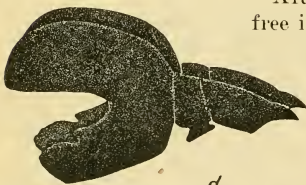
a



b



c



d

FIG. 2.—*Zygobothria nidicola*: a, Mouth hook of first-stage maggot, dorsal aspect; b, mouth hook of first-stage maggot, lateral aspect; c, mouth hook of second-stage maggot; d, mouth hook of third-stage maggot.

FIRST-STAGE MAGGOT OF THE PARASITE.

The most striking thing about the parasitic maggot at the time it enters the caterpillar is the strongly chitinized mouth hook (Fig. 2, a, b). It is simple in this stage, consisting of a single apical tooth and comparatively narrow, divided, posterior plates, the entire mouth hook being one solid structure. A pair of rather indistinct spiracles open on the last body segment.

After entering its host the parasite lives free in the body cavity for about 10 to 14 days and feeds on the fat body of the slowly developing caterpillar. Then it enters the œsophagus and remains here throughout its hibernation period of about nine months. It may lie longitudinally disposed or it may lie obliquely; apparently no particular part of the œsophagus is preferred, but usually the head of the parasite is directed toward the anterior end of its host.

From dissections it appears that the maggot lies in a cyst against the inner wall of the intestine. Here, of course, it does not feed at all.

Rather severe competition is encountered from two hymenopterous parasites, *Apanteles lacteicolor* Viereck and *Meteorus versicolor* Wesmael, which also hibernate in the small brown-tail moth caterpillars. The presence of either of these parasites in the same host with *Zygobothria* produces the death of the latter. The exact nature of this peculiar influence exerted by the hymenopterous parasites upon the dipterous larva has not yet been demonstrated. Death

may perhaps result from a direct secretion of the hymenopterous species, or it may follow some special reaction on the part of the host; at no time has evidence of active combat been found.

In the spring the brown-tail moth larvæ that have hibernated begin feeding as soon as the buds open, but the *Zygobothria* maggots, in their cysts in the œsophagus, remain inactive for several weeks longer. It is not until late May and early June, when the host larvæ have molted into the last stage, that the parasite leaves its cyst in the fore-intestine and again enters the body cavity of the caterpillar to feed. Invariably it works its way at once to the posterior end of the host. After three or four days it is found to have established communication with the outside air through an opening in the integument of the brown-tail moth larva. From this minute, more or less circular opening there proceeds a rapid growth of the integument into the body cavity. This ingrowth takes the form of a funnel, within which the parasite lies, its posterior end directed toward the small opening, its anterior end free in the fat and fluids of its host. Thus the parasite has procured for itself an independent air supply. On the outside of the integumental funnel layers of soft tissue, evidently consisting of hypodermal cells, leucocytes, and compressed fat cells of the caterpillar, are gradually laid down, one upon another, until a thick, fleshy wall has been formed about the funnel.

The manner in which the opening through the body wall of the brown-tail moth larva is effected was not observed. Possibly it results from irritation by the spines at the caudal end of the parasitic maggot.

SECOND-STAGE MAGGOT OF THE PARASITE.

Very soon after becoming established in the posterior end of its host, and in the integumental funnel, the parasite molts into the second stage. The first-stage skin is pushed back upon the funnel where it is readily detected by the presence of the mouth hook. The second-stage maggot is distinguished from that of the first stage by its larger size, the much heavier mouth hook, and the presence of a pair of anterior spiracles, often difficult to locate, situated between the second and third body segments. Instead of the single apical tooth of the first stage the mouth hook now has two teeth, the pharyngeal skeleton having divided longitudinally over its anterior half; furthermore, there is now an indistinct transverse joint near the middle of this anterior portion. The posterior plates of the mouth hook are much stouter than in the first stage.

Throughout this instar, which requires from 8 to 12 days, the maggot remains in the integumental funnel. It grows rapidly during this period so that it measures about 4 mm. in length when ready to molt into the third and last larval stage. By this time the host has spun its cocoon.

THIRD-STAGE MAGGOT OF THE PARASITE.

When the second-stage skin is molted it is pushed back upon the funnel, as was that of the first stage; the mouth hooks of the two instars at this time are easily seen on the mass of yellowish tissue that surrounds the chitinous funnel itself. The particular points of difference between the second and third stage maggots are the larger size of the latter and its much heavier mouth hook. The mouth hook is divided longitudinally as in the second stage, but there are now two joints in the anterior part of the skeleton, one near the middle, corresponding to the single joint of the second stage, and another near the base of the very broad posterior plates. The anterior spiracles, opening between the second and third body segments, are much more distinct than in the second instar.



FIG. 3.—Brown-tail moth caterpillars containing puparia of *Zygobothria nidicola*.

This stage is the shortest of the three, requiring only four or five days. The host larva is killed just before the end of this period, with the destruction of its vital organs, and the parasite forms its puparium in the integumental funnel inside the host.

The puparium is about 8 mm. long and is dark brownish red in color; the posterior end is a little depressed, and the two anal stigmata (Fig. 4) within the depression are slightly elevated. Dead caterpillars that contain puparia of *Z. nidicola* (Fig. 3) are easily detected; they are greatly shortened, being scarcely longer than the puparia within, and are slightly inflated.



FIG. 4.—Anal stigmata of puparium of *Zygobothria nidicola*.

The period spent in the puparium averages from 25 to 30 days, after which the flies appear, some 8 to 16 days prior to the hatching

of the eggs of the brown-tail moth. This is just time enough to insure fertilization and development of the ova. Thus the life cycle of *Zygobothria nidicola* fits perfectly into that of its host.

ECONOMIC IMPORTANCE OF THE PARASITE.

Although *Zygobothria nidicola* has only one generation a year, and is handicapped by its absolute dependence upon the brown-tail moth, it has become a common species in New England. This means that it is of very great importance in the natural control of the brown-tail moth. Especially in the southern part of the infested area has the parasite proved remarkably effective, despite the fact that it is always the loser when in competition with *Apanteles lacteicolor* or *Meteorus versicolor*. In dissections of thousands of hibernating brown-tail moth caterpillars from all sections of New England it has been common to find from 20 to 30 per cent parasitism by *Zygobothria*.

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UNITED STATES DEPARTMENT OF AGRICULTURE



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Washington, D. C.



October 16, 1922

THE GIPSY MOTH ON CRANBERRY BOGS.

By CHARLES W. MINOTT,

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Bureau of Entomology.*

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INTRODUCTION.

While the gipsy moth (*Porthetria dispar* L.) has been in Massachusetts since 1868, that section of the State in which the cranberry industry is established was nearly immune from the ravages of this insect until 1913. About this time, however, owing to favorable conditions, the infestation increased very rapidly in the southeastern part of the State, and occasional complaints were heard regarding injury to cranberry bogs in certain sections of Bristol, Barnstable, and Plymouth Counties. These conditions, and the importance of the cranberry industry, were sufficient causes to warrant a study of the habits of the gipsy moth on this new food plant. Under the direction of A. F. Burgess, in charge of moth work in New England, the writer began a study of the problem in 1916, the results of which are recorded in this bulletin, together with suggestions in

regard to methods of control which may be adopted in cases where this pest becomes a menace to cranberry bogs.¹

ARTIFICIAL CRANBERRY BOGS.

The locations in which cranberries may be grown vary considerably in regard to natural conditions. In Massachusetts, the State with which this investigation more particularly deals and in which more than half of the total crop is produced, the cultivated, or artificial, bogs are constructed in locations where, perhaps, the cranberry once grew naturally, but not necessarily so. They are, however, always located in natural depressions of the land, varying in size from less than an acre to more than 100 acres, in natural swamps or bogs, in which the water table is constantly near the surface of the soil. To protect the plants against damage from frost or against insect injury, it has been found desirable to provide for flowing the bogs with water. Where this can be done the bog is called a wet bog; where not, a dry bog. Each has its advantages; but as a rule wet bogs are preferred.

HOW BOGS BECOME INFESTED WITH GIPSY MOTHS.

The topography of the cranberry-producing sections of Massachusetts is characteristic of the glacial drift of Cape Cod. It is broken by low rolling hills, interspersed with bogs, ponds, and meadows. The uplands immediately surrounding the cranberry bogs, often from 10 to 50 feet high, frequently well wooded, furnish ideal conditions for wind dispersion of first-stage gipsy moth larvæ, the principal means by which both wet and dry cranberry bogs become infested.

When trees are allowed to grow close to and overhang the bog, larvæ may drop or spin down from the branches and reach the cranberry vines. When heavy infestations obtain in the wooded borders and are not destroyed, defoliation is likely to occur, and the larvæ may crawl from the upland onto the bog in search of food and cause serious damage, as these large larvæ feed upon both new and old foliage, even eating the bark from the vines. These are the three principal ways (wind, dropping, and crawling) by which

¹The writer wishes to express his appreciation to A. F. Burgess, Dr. J. N. Summers, and I. T. Guild for their helpful suggestions and advice, which have added materially to the accuracy and value of this paper, and to the last for the map and upland trench drawings; to F. H. Mosher for notes relative to the killing of the embryo in gipsy moth eggs by winter flooding of cranberry bogs; to W. N. Dovener for the enlarged drawing of the terminal bud of the cranberry plant; and to C. E. Hood for the preparation of the photographic illustrations—all of the Bureau of Entomology; to Dr. H. J. Franklin, superintendent of the cranberry substation of the Massachusetts State Experiment Station, Wareham, Mass., for valuable information relative to the growth of the cranberry plant and bog management; and to J. W. Smith, meteorologist in charge of the U. S. Weather Bureau at Boston, Mass., and his assistants for information relative to wind currents, temperature, and the setting up and management of the recording instruments.

cranberry bogs become infested with gipsy moth larvæ. In view of the fact that cranberry foliage is not a very favored food which gipsy moth larvæ seek by choice, and as the bog does not offer favorable conditions for reproduction of the moths from year to year, it is obvious that wind dispersion is an important, if not the most important, factor to be considered in studying the infestation of bogs.

WIND DISPERSION OF GIPSY MOTH LARVÆ.

HISTORY.

The first investigations of wind dispersion of the first-stage gipsy moth larvæ were made in 1910 by A. F. Burgess and recorded in Bulletin No. 119 of the Bureau of Entomology. These investigations established the fact that the young gipsy moth caterpillars, soon after they emerged from the egg, were carried considerable distances by the wind. This was the first indisputable explanation of the origin of isolated infestations in woodlands, as well as those that were frequently located in territory outside of the known infested area. The spread of this insect in a northeasterly direction year by year, it was found, was due to the fact that the wind usually blows from the southwest at the time when the young caterpillars first reach the tops of the trees.

In 1913-14 C. W. Collins carried on a series of experiments to determine the distance young caterpillars would be carried by the wind. The results of these experiments are recorded in Bulletin No. 273 of the U. S. Department of Agriculture, in which it is shown that under favorable conditions the small caterpillars were carried $13\frac{1}{2}$ miles. Later experiments have demonstrated that they may be carried 20 miles, and it is probable that under the most favorable conditions the spread is even greater.

SELECTION OF A BOG FOR EXPERIMENTAL PURPOSES.

Several bogs in the cranberry region were examined and the one that seemed best suited for the experiments was in the northern part of Carver, Plymouth County, Mass. This bog was approximately oval in form, about 3,600 feet long and 2,000 feet across at its widest part. The bordering uplands were typical of the region, consisting of elevations, from 10 to 50 feet in height, well wooded with pine, oak, birch, and some maple, with a few stands made up mainly of oak and birch. Egg clusters of the gipsy moth were found in these bordering woodlands, and were particularly plentiful on the western border. Some sections of this area were already in bog, one portion was in process of reconstruction, and the remainder was the bed of a pond that had recently been drained for the purpose of converting the whole area into one large cranberry bog. (Pl. I, Fig. 2.)

OBSERVATIONS ON WIND DISPERSION.

To determine the number of caterpillars blown upon this bog, traps were located at points shown on the map (Fig. 1) and continuous observations taken during the period in which the larvæ

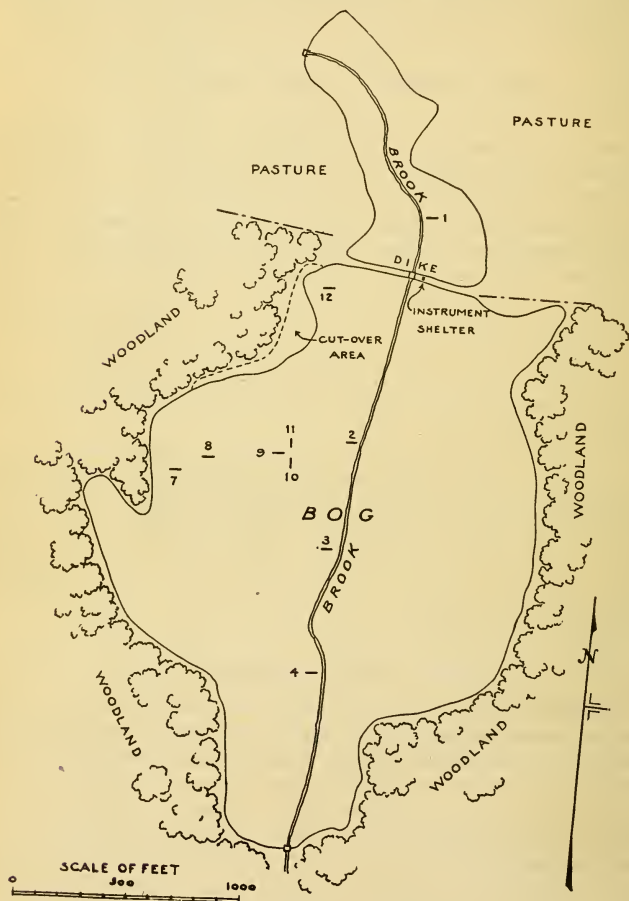


FIG. 1.—Sketch map of Muddy Pond Bog, showing location of traps.

were carried by the wind. Record was made of temperature, with Draper self-recording thermometers, one at the bog level and another at the top of the observation tower described later; and wind



FIG. 1.—GIPSY MOTH LARVA DESTROYING ALL PROSPECTS OF A CRANBERRY CROP.

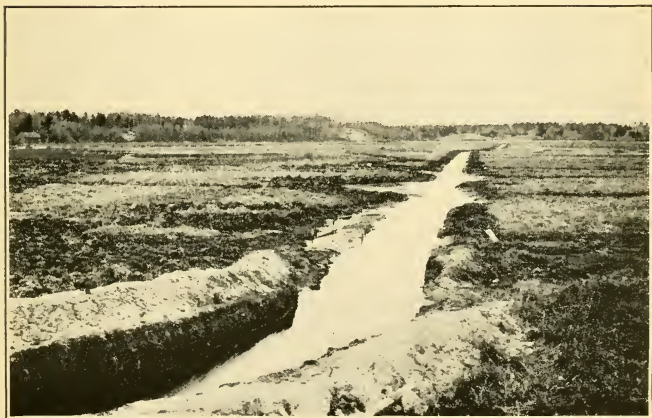


FIG. 2.—GENERAL VIEW OF MUDDY POND BOG, CARVER, PLYMOUTH COUNTY, MASS., LOOKING SOUTH FROM THE DIKE.
THE GIPSY MOTH ON CRANBERRY BOGS.

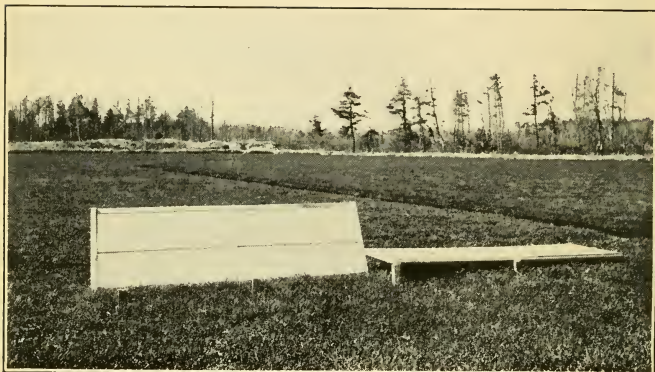


FIG. 1.—HORIZONTAL TRAP USED FOR CAPTURING WIND-BORNE GIPSY MOTH LARVÆ, SHOWING CONSTRUCTION.

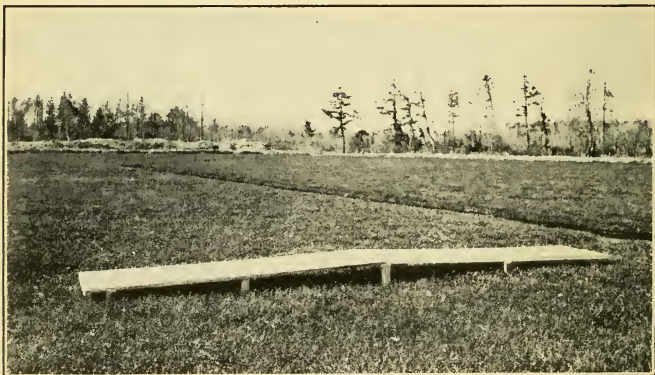


FIG. 2.—SAME TRAP SHOWN IN FIGURE 1 IN PLACE ON MUDDY POND BOG. THE GIPSY MOTH ON CRANBERRY BOGS.

velocity was recorded at a point about 25 feet above the bog level by a Robinson cup anemometer. The direction of the wind was also noted at hourly intervals during the day. The traps made it possible to count the caterpillars falling upon a known area, under given conditions, and at different locations on the bog, and to compare these records from year to year.

DESCRIPTION OF TRAPS.

The traps used by Burgess and Collins in previous wind dispersion experiments were constructed of 1-inch mesh wire poultry fencing, erected in a vertical position, and made in several sizes, their principal object being to demonstrate the certainty of wind dispersion.

A study of the results of these experiments indicates that quite a percentage of the caterpillars, particularly when the wind attained a velocity of 20 miles or more per hour, were blown through the meshes of the wire, notwithstanding the fact that the wire was well covered with commercial sticky tree-banding material. Eight horizontal traps having a solid surface were used in the bog experiments, numbered 1, 2, 3, 4, 7, 8, 9, and 12, and two vertical traps numbered 10 and 11. (Fig. 1.)

The horizontal traps were 20 feet long and 2 feet 8 inches wide, outside measurement. These dimensions were adopted for two principal reasons: First, to facilitate inspection of the surface, and, second, to reduce the danger of wind damage. For convenience in handling, they were made in two sections, each 10 feet long. The framework was made of wood 1 inch thick and 2 inches wide with a strip through the center to prevent the covering from sagging. (Pl. II, Fig. 1.)

Cotton cloth was first used for covering the frame, but this was not satisfactory, owing to its tendency to sag and hold rain water. Wall board was substituted, and proved very effective. Supporting stakes were driven into the bog at such height that when the frame was nailed to them, the two sections sloped from the center toward either end, in order to shed all moisture. (Pl. II, Fig. 2.)

The upper surface of the wall board was given a coat of outside white paint, which helped materially in distinguishing the small gipsy moth larvæ from the myriad of midges and other insects that are caught upon the trap. After the paint was dry the surface was marked off into 64 oblong sections 8 inches wide and 15 inches long. This made it possible to be sure that the whole surface was inspected and saved considerable time in making collections of larvæ that were caught on the trap.

Finally, the whole surface was covered with a coating of commercial sticky tree-banding material about one-fourth inch in thickness to serve as a trap for the caterpillars.

Later, improvements were made by setting the traps practically level, with an additional center support running longitudinally and serving as a ridge, which gave a slight pitch to either side, forming a perfect watershed. They were also raised to stand about 2 feet above the bog surface, particularly to facilitate inspection.

No. 10, the solid-surface vertical trap, was constructed of wall board, with the upper edge of the trap 9 feet above the surface of the bog. Twelve 8-inch holes were cut through the wall board and covered with $\frac{1}{4}$ -inch mesh wire screen in order to reduce the force of the wind, but more particularly to prevent a cushion of air from forming in front of the trap. The whole surface, wall board and wire, was given a coating of commercial sticky tree-banding material as in the case of the horizontal traps. (Pl. III, Fig. 1.) Trap No. 11 was constructed in the same manner as No. 10, with the exception that three-fourths inch mesh wire netting was used for a surface. (Pl. III, Fig. 2.) All traps, with the exception of Nos. 10 and 11, were erected with the longer dimensions running east and west. Nos. 10 and 11 were erected vertically, facing east and west. In order to obtain information regarding the number of caterpillars and how far they were blown onto the bog, these traps were located at varying distances from the bog border.

RECORD OF TRAP OBSERVATIONS.

Trap observations have yielded information in regard to the number of caterpillars carried by the wind and as to the conditions under which they are carried.

The time of hatching the gipsy moth caterpillars is governed by the temperature. It is evident that in order to control infestations on bogs careful attention must be given to this factor. (See Table 1.)

TABLE 1.—*The variation of time in hatching and dispersion of gipsy moth caterpillars during the period covered by observations at Muddy Pond Bog, Carrer, Mass.*

Year.	First hatching noted.	First larvæ taken on traps.	Time of maximum dispersion on traps.	Time between first hatching and maximum dispersion.	Time between first trap record and maximum dispersion.
				Days.	Days.
1916.....	May 9	May 22	May 25-26.....	16-17	3-4
1917.....	19	26	June 3, 4, 5.....	15-17	8-10
1918.....	7	10	May 15-16.....	8-9	5-6
1919.....	6	15	May 18, 19, 20.....	12-14	3-5

As a result of these observations it will be seen that the time of greatest dispersion follows from 13 to 14 days after hatching. It should be noted, however, that on uplands independent observations have shown that this period is shorter.

With the exception of the year 1917, the woodland surrounding Muddy Pond Bog was lightly infested with the gipsy moth. During that year there were a few scattered pockets on the western edge of the bog where a medium infestation existed. No heavy infestations were noted during the years that these experiments were conducted. The results of the observations for 1917 may therefore be taken as illustrating what might reasonably be expected in any similar infestation, and are given in detail in Table 2.

TABLE 2.—*Trap record for the season of 1917 giving the total number of gipsy moth larvæ taken from each trap and total for each day of dispersion, Muddy Pond Bog, Carver, Mass.*

Trap No.	May.		June.											Total.
	26	31	1	2	3	4	5	6	7	8	9	10	14	
1.....	0	4	3	4	24	8	8	3	0	0	0	0	0	54
2.....	4	(1)	12	12	(1)	43	(1)	35	(1)	3	0	4	(1)	113
3.....	3	(1)	10	11	(1)	38	8	8	(1)	2	(1)	(1)	(1)	80
4.....	(1)	(1)	(1)	22	(1)	11	(1)	10	(1)	1	(1)	(1)	(1)	44
7.....	16	11	26	28	169	135	46	10	10	4	2	7	1	465
8.....	11	15	17	12	86	149	54	11	4	5	2	7	0	373
9.....	5	4	9	3	58	47	20	3	2	1	2	3	2	159
Total...	39	34	77	92	337	431	136	80	16	16	6	21	3	1,288

¹ No examinations made.

From Table 2 it will be noted that the largest numbers of larvæ were taken from the traps nearest the border of the bog, the number gradually diminishing as the distance from the border increased.

It is interesting to note the results secured on the two vertical traps. On No. 10, which was constructed of wall board, 255 larvæ were caught, while on No. 11, which was a wire trap, only 121 were secured. As these two traps were placed in equally favorable locations, it is evident that many larvæ passed through the wire screen. It is probable that wire treated with commercial sticky tree-banding material but having one-fourth-inch mesh would be much more effective. It is also interesting to note the difference between the number of larvæ taken on horizontal trap No. 9 and vertical trap No. 10. They had the same number of square feet of surface exposed, and although they were located near together, 159 were taken on the former and 255 on the latter. This shows conclusively that the number of wind-borne larvæ caught on a vertical surface is not a fair index of the number that will drop on a horizontal area of the same size. The density of infestation on low vegetation, when insects are

carried by the wind, should be determined by horizontal rather than vertical traps.

A total of 1,288 first-stage larvæ were taken on 385 square feet of horizontal trap surface, or an average of 3.3 larvæ per square foot.

Table 3 summarizes the information secured on the horizontal traps exposed on Muddy Pond Bog during the years 1916 to 1919. It will be noted that the number of larvæ caught in 1917 far exceeded the total for any other year. This was largely due to a slightly heavier infestation and more favorable weather for wind dispersion when the larvæ were in the first stage.

TABLE 3.—Wind dispersion data for gipsy moth larvæ collated for the four-year (1916-19) period.

Year.	Number of horizontal traps.	Trap surface.	Total number of larvæ trapped.	Number of larvæ taken per square foot of trap surface.	Days of dispersion.	Days of heaviest dispersion.	Larvæ taken on days of heaviest dispersion.	Percentage of total number trapped.
		<i>Sq. ft.</i>						
1916.....	4	240	111	0.4	15	2	72	64.8
1917.....	7	385	1,288	3.3	20	5	1,076	83.5
1918.....	9	500	132	.2	15	5	97	73.4
1919.....	1	55	197	3.9	13	5	172	87.3

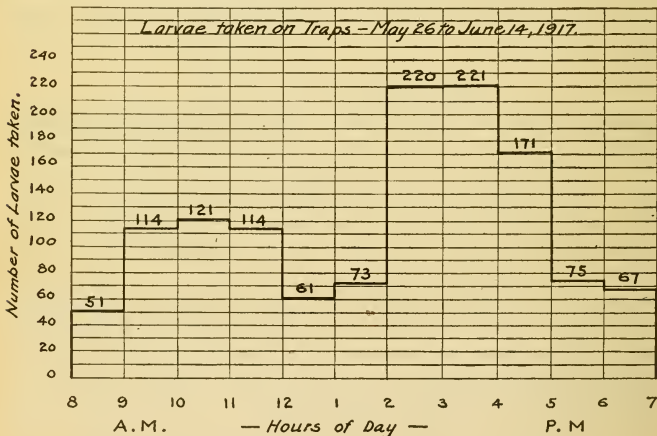


FIG. 2.—Showing two daily periods of maximum wind dispersion.

Figure 2 shows graphically the number of first-stage larvæ taken on the traps during the whole time of dispersion in 1917. This shows very clearly the important fact that there are two daily dispersion

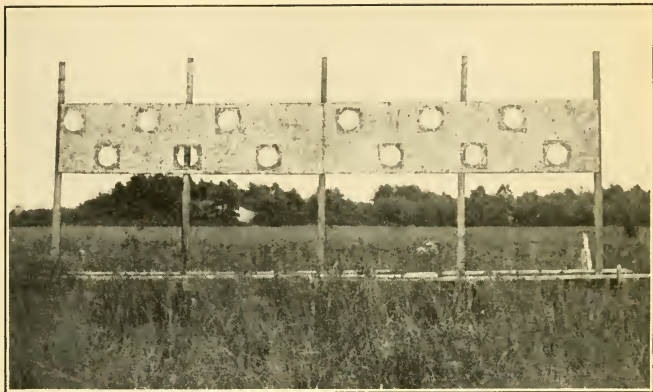


FIG. 1.—VERTICAL TRAP NO. 10, SHOWING CONSTRUCTION.

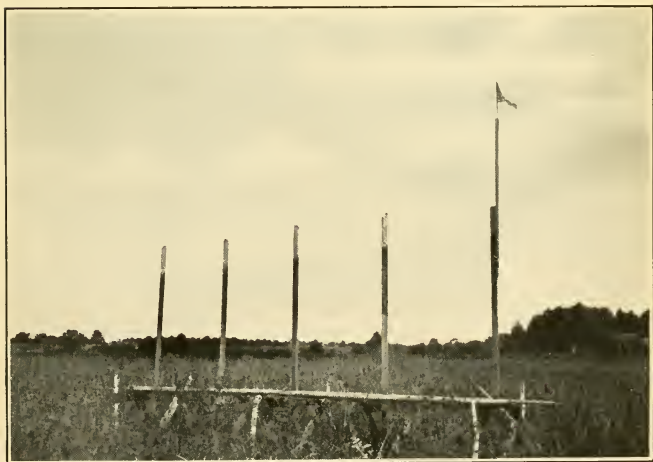


FIG. 2.—VERTICAL TRAP NO. 11, CONSTRUCTED OF WIRE POULTRY FENCING.
THE GIPSY MOTH ON CRANBERRY BOGS.



TOWER SURROUNDING WHITE OAK TREE, FROM WHICH THE FEEDING HABITS
OF FIRST-STAGE GIPSY MOTH LARVÆ WERE STUDIED.
THE GIPSY MOTH ON CRANBERRY BOGS.

periods, viz, 9 a. m. to 12 m. and 2 to 5 p. m.;² and, furthermore, the observations of four consecutive years give substantially the same results. The small number of larvæ dispersed from 12 m. to 2 p. m. is not due to lack of favorable conditions either of temperature or wind velocity, for the mean temperature and wind velocity for that period of the day have both been found very favorable for heavy dispersion. The two periods of dispersion are due to a movement in search of food and are discussed more fully under the heading "Feeding habits on white-oak foliage" (p. 10).

The data from the traps secured from 1916 to 1919 prove that in order to have caterpillars dispersed in large numbers it is essential to have, first, a "medium" to "heavy" infestation; second, a temperature above 70° F.; third, a wind velocity of from 8 to 15 miles per hour. It has been found that a fairly steady wind blowing 10 to 12 miles per hour will disperse more larvæ, other conditions being favorable, than wind of higher velocity which blows intermittently.

FEEDING HABITS ON CRANBERRY FOLIAGE.

Experiments have determined that under laboratory conditions gipsy moth larvæ can not be successfully carried through the several stages on cranberry foliage alone. This information was obtained in 1914 by F. H. Mosher and recorded in Bulletin No. 250 of the U. S. Department of Agriculture. In obtaining this information Mr. Mosher used feeding trays devised by W. F. Fiske, formerly of the Bureau of Entomology, with cranberry foliage inserted in crook-necked vials, filled with water, in order to keep the food fresh.

Bog observations have shown that the young first-stage larvæ begin their feeding on cranberry by attacking the contents of the terminal buds. They first eat through or between the bud scales, and then consume the tender undeveloped leaves within, leaving nothing but a shell formed by the bud scales. (Fig. 3.) By the time the caterpillars have reached the second stage the terminal buds not already

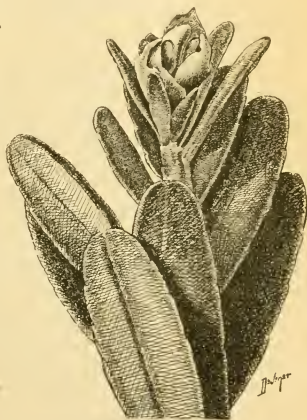


FIG. 3.—Terminal bud of cranberry plant showing injury caused by first-stage gipsy moth larvæ.

By the time the caterpillars have reached the second stage the terminal buds not already

² All observations recorded in this bulletin were made according to Eastern standard time.

destroyed will have expanded into new shoots, and feeding is then confined almost entirely to the stems of these shoots, not to the leaves and buds. (Pl. I, Fig. 1.) In this way a large percentage of the new growth may be entirely destroyed, provided the infestation is sufficiently heavy. The same habit of feeding is continued through the later stages, until the supply of new growth is exhausted, then the older leaves may be attacked, and the vines stripped, provided, again, that the caterpillars are numerous enough to be forced to seek this less attractive food.

It is obvious that a few caterpillars can do a great amount of damage, first to the terminal bud from which is produced the season's fruit, and second by causing a branching growth of the plant. This damage to the terminal bud may occur before the owner realizes that his bog is infested.

FEEDING HABITS ON WHITE OAK FOLIAGE.

In the observations made in 1916-19 concerning the dispersion by wind of first-stage gipsy moth larvæ, it became evident, from the count of larvæ taken from the traps, that there are two periods of the day during which maximum dispersion occurs. From this fact it was inferred that there are, correspondingly, two daily periods of activity, as the larvæ would be more likely to be carried by the wind when crawling over leaf surfaces, limbs, or trunks of trees than when at rest. To verify this inference it was decided to make a study of the habits of first-stage larvæ as they are found in tree tops, where the earliest feeding usually appears, and where also the relation between the feeding habits and wind dispersion could be more satisfactorily studied.

A white oak about 30 feet high was selected near the border of Muddy Pond Bog. Around this tree was erected a tower 16 feet square at the base, 8 feet square at the top, and 25 feet high. A flooring was placed around the branches on top of this tower, thus bringing the upper 5 feet of the terminal branches in position for close examination and observation of the movements of young larvæ. (Pl. IV.)

On May 19, 1919, when observations were started, the leaves on this tree had begun to unfold, some of which would measure an inch in length, giving considerable protection to the young larvæ, as well as supplying food. It was found that the first feeding by first-stage gipsy moth larvæ after reaching the foliage was confined to the leaf hairs, principally on the underside of the leaves. After feeding in this manner for a day or two they began to feed on the tissue of the leaf, later eating through the tissue. The information relating to the feeding periods of first-stage gipsy moth larvæ, collated for the whole period of observation, furnishes what can be

considered as a continuous record from 3.45 a. m. until 7.30 p. m. These observations determined that feeding began soon after daylight, gradually increasing as the temperature increased, until it reached its maximum from 9 to 11 a. m. when it began to diminish, reaching a minimum during the midday, then gradually increasing again, reaching its maximum from 3 to 5 p. m., and gradually decreasing after this hour, a majority of the larvæ seeking shelter on the underside of the leaves by 7 p. m. Wind dispersion records cited show practically no movement of small caterpillars between 11 a. m. and 3 p. m., the period when there is practically no feeding and very little activity.

INJURY BY A GIVEN NUMBER OF LARVÆ.

When a new cranberry bog is planted the vines are usually set in rows 12 inches apart, and the same distance in the row. The increase of the vine area is by runners radiating out from each plant, in all directions, eventually forming a dense mass of vines over the whole bog surface. From these runners upright shoots grow, and under normal conditions increase in height by growth from a terminal bud, and it is upon this new growth that the fruit is borne each season. It is evident that any injury to the terminal buds reduces the amount of fruit in proportion to the number of buds destroyed. With the object in view of obtaining some definite information on this question an experiment was undertaken to determine the amount of damage to cranberry vines that would result from a heavy infestation of gipsy moths. Three pens were built 3 feet square, inside measurement, with sides $2\frac{1}{2}$ feet high. On the outside of each pen, 6 inches from the top, four strips of board were attached at an angle of 30 degrees. Each pen was then forced into the bog about 6 inches and the sand firmly tamped both inside and outside of pens to prevent escape of larvæ. On the underside of this overhang and 6 inches from the top on the inside of each pen bands of commercial sticky tree-banding material were applied in order to prevent the escape of larvæ that were placed on the square yard of vines inclosed and to prevent other insects from gaining entrance to the pen. (Pl. V, Fig. 1.)

From year to year during the period covered by these studies varying numbers of first-stage larvæ have been placed in these pens each season and the injury to the vines, as well as the feeding habits of the larvæ on cranberry foliage, has been carefully noted.

The results of these experiments have shown that an infestation of two larvæ to the square foot has destroyed nearly all the new growth of cranberry foliage. An infestation averaging one larva

to the square foot would materially reduce the crop and would necessitate flooding or spraying in order to prevent damage.

Plate VI, Figure 1, shows a section of the surface of the vines in the above-mentioned pen and when compared with Plate VI, Figure 2, showing a similar area just outside of the pen, on the bog proper, with the vines in full bloom, the loss of the new growth is manifest.

MORTALITY OF FIRST-STAGE LARVÆ.

General observations on Muddy Pond Bog, particularly in connection with the pen experiments, have shown that there is a varying percentage of mortality among the several larval stages of the gipsy moth, after they reach the cranberry vines. This mortality is probably greatest in the first stage, owing to several factors. The principal factor is reduced vitality, since larvæ hatching from egg masses that were deposited upon conifers or other nonfavored food species had used up a considerable percentage of their vitality in searching for food before they were blown from the tree onto the vine surface. Their vitality was further reduced in crawling over the vines before approaching starvation finally forced them to feed upon the buds or new stalks of the cranberry vines. While in this weakened condition the larvæ are more susceptible to cold, particularly when accompanied by rain. That there is quite a difference between the temperature at the tops of trees and that at the bog surface was demonstrated by the use of recording thermometers. The platform at the top of the tower constructed around the white oak tree on which feeding observations were made was about 50 feet above the bog level. A comparison of the thermometer records made at the top of the tree and at the surface of the bog shows that the temperature averaged 5.2° F. cooler at the bog surface than at the top of the tree for the night period during the 6 days of heaviest wind dispersion, viz, May 25 to 30, inclusive. From 6 p. m. May 29 to 5 a. m. May 30 the average temperature was 11.3° F. lower at the bog surface than at the top of the tower. At 1 a. m. May 30 it was 15° F. lower at the surface of the bog than in the tree top, the maximum difference in the locations during the period. This was the coldest night of the period, and gave the greatest range of temperature. The above temperatures were obtained from the thermometers in latticed shelters.

There is also a high mortality among first-stage gipsy moth larvæ on cranberry bogs due to disease, predacious enemies, and other causes that are not well understood. All of these agencies, together with the rather unfavorable nature of the cranberry foliage as a food, combine to bring about an enormous reduction of the wind-blown larvæ.

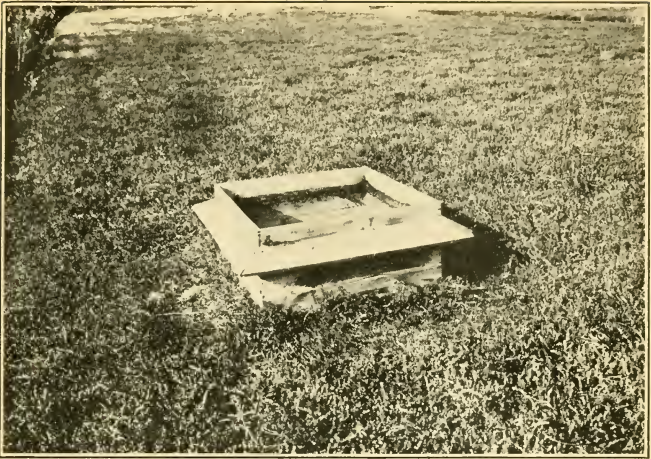


FIG. 1.—PEN USED TO CONFINE GIPSY MOTH LARVÆ WHILE STUDYING THE INJURY CAUSED BY THEIR FEEDING ON CRANBERRY PLANTS.



FIG. 2.—SHOWING AN UNEVENLY GRADED CRANBERRY BOG FLOWED TO DESTROY WIND-BORNE GIPSY MOTH LARVÆ. EXPOSED PORTIONS SHOULD BE SPRAYED TO INSURE COMPLETE PROTECTION.

THE GIPSY MOTH ON CRANBERRY BOGS.

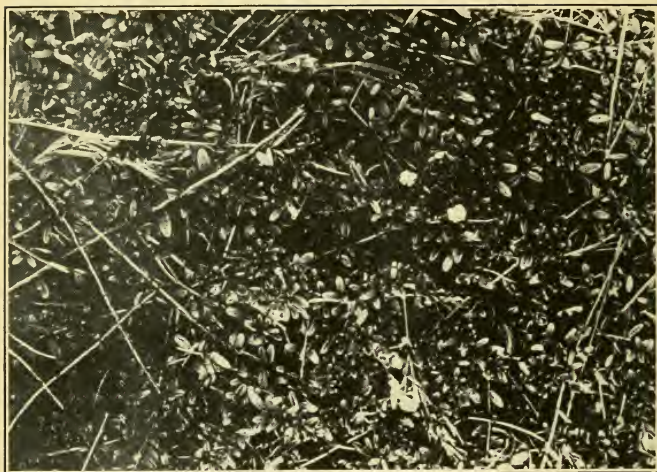


FIG. 1.—SECTION OF CRANBERRY FOLIAGE INSIDE OF PEN, SHOWING INJURY CAUSED BY 36 GIPSY MOTH LARVÆ. NOTE ABSENCE OF BLOOM. PHOTOGRAPHED JULY 12, 1917.

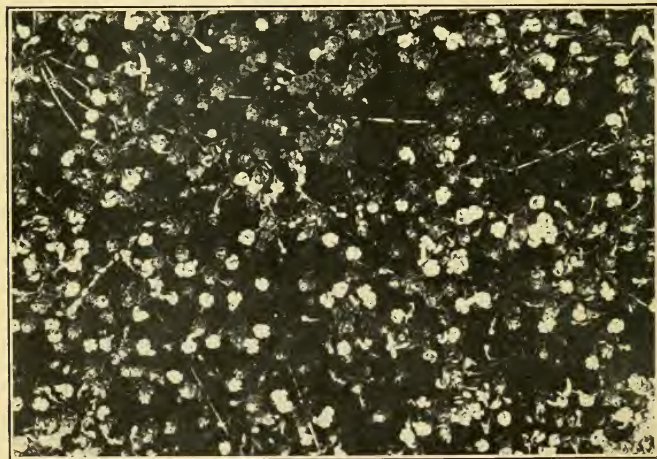


FIG. 2.—SECTION OUTSIDE OF PEN WHERE NO FEEDING BY GIPSY MOTH LARVÆ OCCURRED. PHOTOGRAPHED JULY 12, 1917.
THE GIPSY MOTH ON CRANBERRY BOGS.

RECOVERY OF CRANBERRY VINES FROM GIPSY MOTH FEEDING.

The soils of cranberry bogs are bound to vary in different bogs, owing to location, character of the peat constituents, and variation in grading. Often it is necessary to remove nearly all the peat in some sections of a bog in order to get the proper grade. When such conditions occur there is an uneven distribution of water; consequently the resulting crop will vary and the recovery of vines after injury will vary.

Muddy Pond Bog would be rated as a dry bog during the whole period that observations have been carried on. Whenever defoliation has occurred it has meant the loss of a crop for two years. After the buds or new growth were destroyed the vines would make a second growth from dormant buds, but would not form fruit buds. The second year, if no feeding occurred, the vines would make a normal growth and develop strong fruit buds, which would produce a heavy crop of berries the second year from defoliation, provided no climatic or insect injury prevented. Observations on wet bogs with a controllable water supply have shown that when the vines suffer the loss of the terminal fruit bud or of the later new growth, they usually make quick recovery, putting forth a strong second growth, and develop vigorous fruit buds. In a number of such instances a heavy crop of fruit has been produced the year following.

METHODS OF CONTROL.

The first requisite in the fight against a noxious insect is an accurate knowledge of its life history and all that pertains to its increase or decrease in the field. It is usually found that at some particular stage of its life it is more vulnerable than at any other. After this stage has been determined, the most effectual measure for control or extermination can be employed.

Observations on the mortality of first-stage gipsy moth caterpillars have demonstrated the fact that soon after hatching from the protective egg mass they are very susceptible to injury by cold, and large numbers are destroyed at this time; particularly is this true should beating rains occur accompanied by low temperatures. *At this stage of their development they are most readily killed by a thorough application of an arsenical poison, and a comprehensive grasp of this fact is of vital importance to cranberry growers for efficient and economical control of this pest on cranberry bogs.*

HOW TO DETECT AN INFESTATION.

It is very difficult to detect first-stage gipsy-moth larvæ on cranberry foliage owing to their habit of dropping to the surface of the

bog when the vines are disturbed. One may obtain an approximate idea of the degree of infestation on his bog by either of the following methods, the accuracy of the estimate depending upon the care taken in performing the operation.

PAN METHOD.

Place a bright tin pan carefully among the vines, holding it with the right hand, inclined to the right at an angle of 45 degrees. With the left hand give the vines directly in front of the pan two or three quick slaps; then remove the pan and note the number of gipsy moth larvæ taken. Repeat this operation every 10 or 20 feet, until the whole bog is covered. By keeping a record of the number of larvæ taken and the number of times the pan was used, one may estimate the degree of infestation quite accurately.

INSECT NET METHOD.

The degree of infestation on bogs may be determined also by the use of an insect net. Care should be taken to make even sweeps with the net, covering the same amount of vine surface with each sweep. By counting the number of larvæ taken after making a number of sweeps and estimating the area of vine surface covered by each sweep, one may estimate the infestation on the bog as a whole. The accuracy of this estimate will depend on the care taken in making the sweeps and the percentage of bog area covered. Whichever method is used, the line of collection should be from the shore line of the bog toward the center, as the infestation is usually heaviest nearer the shore.

CONTROL ON WET BOGS.

It has been demonstrated that no hatching occurs from gipsy moth egg masses placed among cranberry vines on bogs that are flowed from December 1 to May 1, while check experiments have shown normal hatching. It has also been found that egg masses placed under sand on dry bogs fall only 6 per cent below normal hatch.

These determinations were made during the winter of 1915 to 1916 and in 1917 by F. H. Mosher, who carried on experiments at North Saugus, Mass., and East Carver, Mass., to obtain information on this phase of gipsy moth investigations.

It is, therefore, evident that the methods of control adopted by the cranberry grower must be governed by the kind of bog infested, whether wet or dry. Owners of cranberry bogs located near an abundant supply of water, where flooding either by gravity or pumps can be quickly accomplished, have at hand the cheapest and most effective method for the control of this pest: First, by winter flowing, by means of which the partially developed larvæ in all eggs depos-

ited on the bogs during the previous season are destroyed; and, second, by holding the flowage until after the maximum time of wind dispersion has passed, which will result in drowning the young caterpillars that fall in the water. It is probable that the low temperature of the water is an important factor in the death of the caterpillars. It may be desirable to hold the winter flowage late, say from the 1st to the 15th of June, in order to control the blackhead cranberry worm (*Rhopobota naevana* Hbn.). When this is found desirable, it is evident that the gipsy moth infestation may be controlled at the same time. It is also probable that some of the other cranberry insects may be controlled in combination with efforts against the gipsy moth.

Observations have demonstrated that the maximum dispersion of first-stage larvæ of the gipsy moth occurs about 13 or 14 days after the first hatching is noted, but this period varies with the season; if there are 5 or 6 days when the temperature ranges from 75 to 85° F., or higher, rapid hatching will occur, and if it continues quite warm, the larvæ will reach the tops of trees sooner, resulting in an earlier dispersion. The best guide to determine when this may occur is the development of white oak leaves. When the leaf buds begin to unfold it is safe to assume that the temperature has been high enough to cause hatching of gipsy moth eggs.

Should the spring be late and the average temperature be low before hatching, and continue so after hatching, then the dispersion period will be correspondingly delayed, and extended over a longer period; in any case, however, there is a time of maximum dispersion, and this will occur, as stated, about 13 or 14 days after the first hatch. The closer the bog owner watches the upland conditions the better able he will be to control effectually an infestation on his bog.

In control by flooding, only complete submergence is effectual. If through lack of sufficient water, or irregularities in the surface of the bog, there are sections where a considerable number of vine terminals are out of water (as shown in the right center of Plate V, Figure 2, and to a less degree through the central section), even with a light to medium infestation on a bog these terminal shoots become actual life rafts for hundreds of larvæ that have crawled up the vines as the flooding gradually progressed, or reached them as the larvæ were blown over the surface of the water by the wind. When any considerable number of these terminal shoots project above the water it is imperative that the larvæ be brushed from the vines by using a common hand hayrake, drawing and pushing the vines under water several times with the back of the rake head. Unless this is done, there is likely to be considerable damage on these partially submerged sections of the bog. In the immediate foreground and

on the right of Plate V, Figure 2, there will be noted sections of the bog entirely out of the water. Flooding will not control an infestation in such cases. These must be controlled by spraying.

CONTROL ON DRY BOGS.

Gipsy moth infestations on dry bogs can be controlled only by intelligent application of some arsenical poison, either in the wet or dry form. It is probable that with more efficient apparatus for the application of dry poison, it will be the most economical and satisfactory way of applying poison to cranberry foliage. The leaf of the cranberry vine being glabrous, it is very difficult to get poison spray to adhere in sufficient quantities for satisfactory results unless the poison is applied in mist form. *Great care should be taken not to allow the mist to continue long enough in one section to reach beyond the dew point. If this should occur, the liquid will run off, leaving only a very thin deposit of the poison on the leaves, not enough to destroy the larvæ present.*

Observations have shown that in case of an infestation on a dry bog, resulting from egg masses deposited the previous season, it is imperative that the application of poison should be made soon after hatching is noted on the uplands, and also that it should be applied in a mist form in order that the largest amount of poison possible may settle on the terminal bud. It is important that the bud be covered thoroughly in order that the larvæ may get enough poison to cause death before they can eat so far into the buds as to cause injury. Six to eight pounds of arsenate of lead paste (or one-half of this amount of dry lead) to 100 gallons of water should effectually control gipsy moths in the first two larval stages if properly applied.

If during the first stage only light winds prevail, dispersion will be minimized, and the central areas of medium or large sized bogs may not become infested to such a degree that spraying will be necessary over the whole area. Careful tests should be made by the pan or net method to determine the degree of infestation along the bog border nearest the infestation on the upland, should there be any, and spraying operations governed accordingly. This applies to wet bogs in case it is not desirable to control an infestation by flooding.

Should a bog be infested with the later larval stages of the gipsy moth, from whatever cause, the only recourse is to spray with a strong solution of arsenate of lead—using from 12 to 15 pounds of lead paste to 100 gallons of water, and using the same care in application as advised for the first larval stage.

CONTROL ON UPLANDS.

After the gipsy moths have reached the second stage, and all danger of wind dispersion is reduced to a minimum, heavy infestations may occur on the uplands in the vicinity of cranberry bogs, and if heavy enough to cause defoliation the caterpillars, in their march for a supply of food, may move in the direction of a bog, and owing to the large amount of food necessary to maintain the hordes of larvæ, may become a serious menace to the bog itself.

There are several methods of control that may be used to advantage in such an emergency, and one or more of those mentioned below should be adopted in order to protect the bog.

The woodland border of the bog may be cut back for the space of 100 feet or more, and possibly the section of woodland from the edge of this cutting to the infested area may be sprayed. If, however, this distance should happen to be only a few hundred feet, the spraying would not accomplish the desired result, because only a few of the thousands of larvæ present would consume enough of the poisoned foliage to cause death. The others would march on in search of more food.

When such conditions occur, an open ditch on the upland, back from the bog border, may be dug, 12 to 15 inches deep and 18 inches wide, the earth being thrown toward the oncoming horde of larvæ, and the side of the ditch nearer the bog being made perpendicular. At the top of this perpendicular side a board about 1 foot wide should be placed at an angle of 45 degrees, overhanging the ditch, supported by stakes driven into the soil; earth should be banked on the outside of this board in such a way as to close up all spaces at the base of the board caused by the irregularities of the surface of the ground. The undersurface of the board and supports should be well smeared with a commercial sticky tree-banding material before being placed in position. The larvæ upon reaching this band will fall into the ditch, and should be sprinkled with crude oil from an ordinary watering pot. In case of extremely heavy infestations it may be necessary to clean out the mass of dead larvæ before the last hordes reach the ditch. (Fig. 4.)

If a protective belt is already cut around the bog it is highly desirable that all sprout growth be kept down by bruising the sprouts from the stumps for two or three years, using a dull ax with which to perform this operation, mowing all other small growth close to the ground, and burning all the débris. This well-cleaned border may help greatly in controlling some of the other insects that breed on the upland border, thereby reducing their ravages on the bog itself.

When light infestations are present and the immediate upland border is clear of overhanging brush, border ditches may offer all necessary protection, provided they are in proper condition. To be effectual they should not be less than 15 inches wide and from 15 to 20 inches deep with the bog side of the ditch perpendicular and as smooth as possible, in order to give little foothold to the crawling larvæ. If not detrimental to the vines or crop, a few inches of water should be maintained in the ditch with a little crude oil on the surface. The larvæ dropping from the land side into the ditch will become smeared with oil and suffocate. Should some larvæ reach the bog side and attempt to crawl up the smooth surface, being weakened by partial suffocation they will drop back into the oil bath.

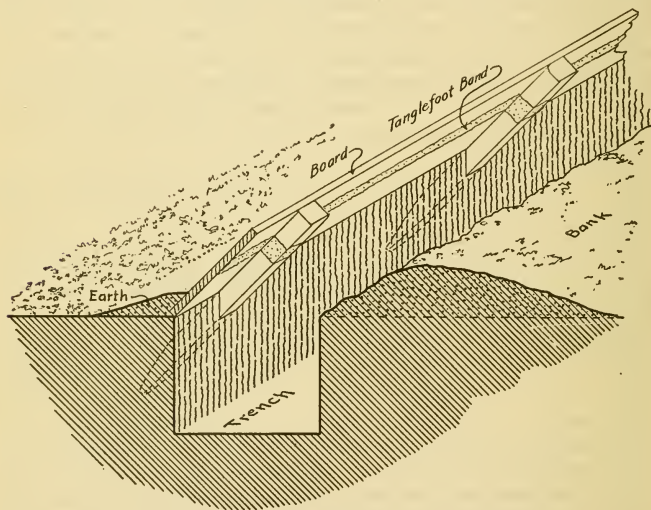


FIG. 4.—Cross section of an upland trench, with board in position.

Should the infestation prove too heavy to be controlled by the oil and water a board about 1 foot wide may be set against the smooth surface of the bog side of the ditch, resting on stakes driven in the bog at an angle of 45 degrees, care being taken to make tight joints. The underside of the board and stakes should be smeared with a good coat of commercial sticky tree-banding material. It is obvious that with an infestation heavy enough to require the use of the board, the ditch might have to be frequently cleared of the dead bodies of the larvæ in order to remain effective.

The method to be used for the control of an upland infestation must be decided by the owner of each bog. He must be governed by the condition and particular surroundings of the bog in question. Any of the foregoing methods should give satisfactory results if attended to properly.

SUMMARY.

Infestations of gipsy moths upon cranberry bogs are due principally to wind dispersion of first-stage larvæ, which occurs only when conditions of wind velocity and temperature are favorable. The time when maximum dispersion prevails is usually not longer than from two to five days. Because of the activity of the young caterpillars in seeking food there are two daily periods of maximum dispersion, between 9 a. m. and 12 m. and between 2 and 5 p. m.

Mortality of first-stage larvæ is very great, large numbers perishing from low temperatures, unfavorable food, predacious insects, and disease. The embryos in all gipsy moth eggs deposited on cranberry bogs are killed by winter flowage, when the bogs are flowed from December 1 to May 1.

Upon deciduous foliage in general the feeding of the first-stage larvæ is upon the leaf hairs, but the injury to cranberry plants is caused by feeding upon the terminal buds, and later upon the new growth. As a rule vines recover more quickly from injury upon wet bogs than upon dry ones.

Flooding is the most effective method of control upon wet bogs; but spraying is the only method which can be employed on dry bogs. *In order to obtain the most satisfactory results, spraying should be done before wind dispersion begins.*

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IMPOUNDING WATER IN A BAYOU TO CONTROL BREEDING OF MALARIA MOSQUITOES.

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INTRODUCTION.

Malaria is responsible for important losses in returns from agricultural crops in the Delta region of the lower Mississippi Valley. The disease is, as well, a great handicap to the further development and extension of agriculture in that region. The prevailing system of labor in the Delta is that of the negro tenant farmer, and it is among this class that the disease is highly prevalent, causing losses

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in time and in reduced efficiency of the plantation hands during the season of the year when the crops are most in need of attention.

The bayous or streams of the region are an important source of the *Anopheles* mosquitoes which convey malaria, and since the higher ridges offered by the bayou banks are the logical locations for the plantation roadways, the homes of the tenants are located along these banks. While control of the breeding of *Anopheles* in a bayou is but one factor in the ultimate control of the malaria mosquitoes in the Delta, it is an important factor, for these bayous offer a near-by source of *Anopheles* in locations on the plantations which are otherwise favorable in respect to distance from breeding areas of these mosquitoes.

Since the general topography of the Delta and the slight fall in the bed of the bayous do not permit drainage, the common practice in disposal of surplus surface water, it became necessary to devise some method of control, practical from the standpoint of plantation management, to prevent breeding of *Anopheles* in bayous. The Bureau of Entomology has demonstrated that the breeding of *Anopheles* mosquitoes can be controlled in a bayou by clearing the vegetation and impounding the water. The work was located on Hecla plantation at Mound, Madison Parish, northeastern Louisiana. This bulletin deals with the natural conditions of the bayou before the work was done and with the changed conditions brought about by the work, especially with reference to the breeding of mosquitoes. It also discusses the impounding of water in a bayou from the standpoint of plantation economy.

TOPOGRAPHY AND FORMATION OF THE REGION.

To gain an idea of the relation of the streams of this region to the surrounding topography, it is necessary to discuss in a very general manner the formation of the region. The soil is an alluvial deposit of considerable depth and the formation is characteristic of delta accumulations. There is a slight fall in the general direction of the main stream, the Mississippi River. This river in times past has followed an irregular, winding course through the Delta of its lower valley, often forming new channels. The old channels are marked by the ridges which are peculiar to the region. The bayous, or streams, of the region are in reality old spillways of the river when at flood, formed before the days of the protective levee system by the tendency of the river at stages of high water to break through its built-up banks and form new channels for the surplus water. Before the levees were built, the river and these bayous overflowed their banks at regular seasonal intervals. The heavier particles carried by the water in suspension were deposited first and in larger quantity. The finer particles were deposited in smaller amounts as one

proceeds from the banks of these streams to either side. The deposits from these overflows account for the ridges along the bayous and the ancient channels of the river. There is, therefore, a gradual fall from these ridges to the lands that lie on either side. These lower lands are extensive swamp areas in the basins of which are found permanent swamp "lakes" which are extremely shallow. The banks of the bayous are formed with a steep declivity toward their channels in contrast to the gradual slope toward the swamp areas that lie parallel to them. The region is further characterized by narrow, crescent-shaped lakes within well-defined banks of the old beds of the river, known as "ox-bows" or "cut-offs," formed where the action of the river has cut a new channel through the neck of one of its many horseshoe bends. The ends of these "cut-off" lakes are usually shallow, showing marshlike conditions, but the main body of water is open and comparatively deep. The bayous are not connected with these lakes except during periods of high water. The swamp lakes tend to drain into the bayous at points lower down in the courses of these streams.

FAVORABLE CONDITIONS FOR MOSQUITO DEVELOPMENT.

The swamp areas and the channels of the bayous are attended by a rank growth of vegetation consequent upon the fertile nature of the alluvial deposit and the prevalent moisture which, with the resulting sediment and vegetable débris, promotes an ideal environment for the development of certain species of mosquitoes under favorable climatic conditions. The situation becomes increasingly emphasized by reason of the imperfect drainage due to the slight fall of the land. Among the mosquitoes, *Anopheles* are found to thrive, and the disease which they convey is prevalent among the inhabitants of the region.

LOCATION OF CULTIVATED LANDS, ROADWAYS, AND DWELLINGS.

In the Delta the timbered lands are practically synonymous with the swamp areas. The open lands, or lands under cultivation, are confined to comparatively narrow strips along the ridges that form the banks of the river, the bayous, and the old courses of these streams. These lands are known as the "front" lands and from the nature of their deposits are sandy in character. The lands lying toward the swamp areas are known as the "back" lands and are a heavy clay, impervious to water, called "buckshot."

The roadways of the region follow the higher lands and, wherever practical, are carried along the bayou banks. The open land is cultivated under the negro tenant system, each tenant living upon the land assigned to him for cultivation. It is therefore logical to find the homes of the tenants on a roadway along the bayou where

one of these streams bounds or sections a property. The houses thus located are in the higher and more open portions of the plantation and usually at maximum distance from the timbered and swamp areas on either side. It is evident that such location of the habitations is favorable in respect to distance from the breeding areas of *Anopheles* mosquitoes, with the exception of those mosquitoes that originate in the bayou itself.

PROBLEM OF ANOPHELES CONTROL IN THE REGION.

Of course complete drainage of surface water is the logical method of *Anopheles* control where that method applies, but in the absence of a drainage outlet, and in the presence of surface water favorable for *Anopheles* breeding throughout the season, other means must be given local consideration. In any consideration of drainage in the Delta it is necessary to note that the streams of this region flow away from the river, that the slope of the land is from the bayou bank toward the swamp areas on either side, and that the fall in the bed of the bayou averages less than a foot to the mile. Under these conditions the question of drainage involves an extensive area; it is not a matter which the plantation owners can consider individually.

The idea of impounding water to suppress mosquito breeding is rather foreign to the general conception of the effect of impounded water upon mosquito production. The relation which impounded water will bear to mosquito production depends altogether upon the conditions under which the work is done and the changes brought about in comparison to the natural conditions. In the question of impounding water in a bayou we must consider the natural character of such a stream and the relation of the stream to the roadways of the plantation and the habitations of the people who cultivate the land. The bayou bank is the logical location for the houses of the tenants and it is important to control the breeding of *Anopheles* in this nearby source. The bayou under natural conditions favors mosquito production but under impounded conditions does not. The change in conditions is brought about by the preliminary clearing and by the provision for a permanent water level sufficiently high to suppress the growth of aquatic vegetation. Following these operations, the maintenance of a clean margin is all important.

BAYOU WALNUT AND THE ANOPHELES SURVEY.

The work of the Bureau of Entomology was done in a section of Bayou Walnut which quarters the southwest portion of Hecla plantation. This bayou runs a very irregular course from a point slightly north of Milikens Bend on the Mississippi River to Bayou Roundaway, joining the latter stream southwest of Tallulah. From the



View along channel, Bayou Walnut, natral conditions, showing overhanging vegetation. Note log and "floatage" on surface of water.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.



FIG. 1.—View along channel, Bayou Walnut, natural conditions, showing overhanging vegetation and aquatic vegetation in bed. Surface of water in foreground covered with duckweed (*Lemna* spp.) and with aquatic plant, *Jussiaea diffusa*, in background.



FIG. 2.—View across Bayou Walnut, natural conditions, showing absence of overhanging vegetation, with aquatic grass, *Zizaniopsis miliacea*, in bed.

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point of origin of the bayou to its junction with Roundaway, the distance in an air line is only $7\frac{1}{2}$ miles. The bayou, however, travels a distance of over 31 miles. The section of Bayou Walnut in its course through Hecla plantation is shown in Figure 1. The average fall of the bayou in this section is 0.6 foot to the mile.

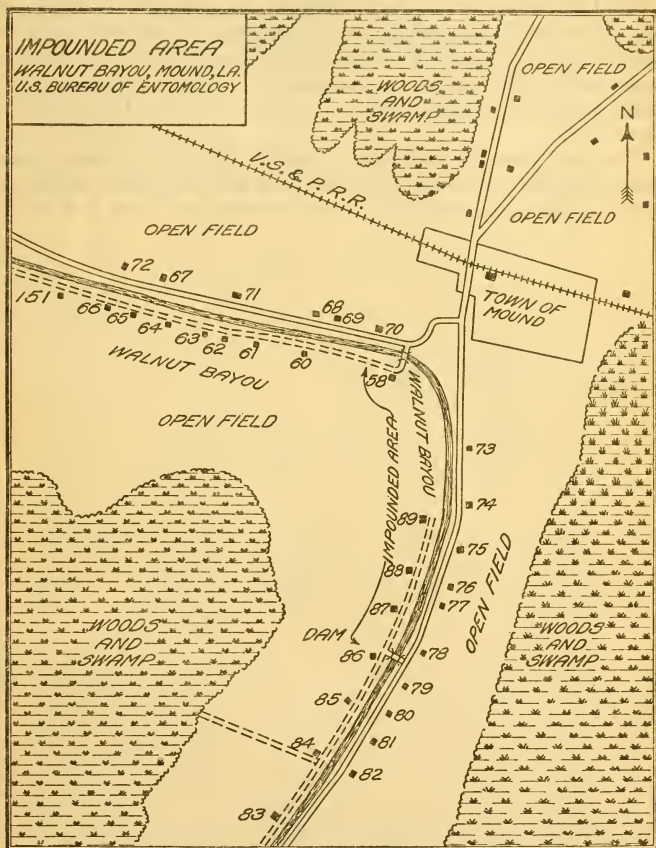


FIG. 1.—Map of section of Bayou Walnut near Mound, La., showing impounded area and surroundings.

During 1914 it was observed that, under natural conditions there was practically no breeding of *Anopheles* in certain restricted sections of the bayou where open water occurred, where the bed was free of vegetation, and where the margins were clean. On the other

hand, breeding was found in those portions of the bayou where the margins were grass-grown or supported a growth of overhanging trees and vines; where the water surface was covered with the resulting vegetable débris or floatage; where the water was shallow enough to support the growth of aquatic vegetation in the bed of the stream; where the channel was blocked by trees, logs, stumps, and brush; or where the bed was partially dry, permitting the summer rains to maintain isolated pools in natural depressions, in hoofprints of animals, and in mud cracks. A comparison of these conditions in the natural bayou is shown in Plates I and II and Plate III, Figures 1 and 2.

The collections of *Anopheles* larvæ in the general survey work during the years 1914 and 1915 gave, for Bayou Walnut within the limits of Hecla plantation, the records which are shown in Table 1.

TABLE 1.—Collections of *Anopheles larvæ*, Bayou Walnut, Mound, La., 1914-15.

Date.	Record No.	Locality.	Water.		Vegetation.	Character of location.	Amount of Shade.	Gambusia present.	Species.
			Depth.	Temp.					
1914. Aug. 10 11 22	4258	H74-75.....	Inches. 1-5	° F. 104	Weeds.....	Margin.....	Open.....	Common.....	Species undetermined. Do.....
	4259	H76.....	5	84	Grass.....	Channel.....	Shade.....	do.....	Quadriramaculatus.
	4266	H77.....	5	89	Smartweed.....	Margin.....	Part shade.....	Abundant.....	Quadriramaculatus, punctipennis.
	4323	H73.....	3	90-94			do.....		
1915. May 26 June 3 8	4701	H89.....			Grass.....	Channel.....	Shade.....	do.....	Crucians. Quadriramaculatus.
	4712	Below dam.....			Duckweed.....	Margin.....	Open.....	Common.....	Do.....
	4724	Station 9.....			Grass.....	Channel.....	Shade.....	Abundant.....	Species undetermined. Quadriramaculatus.
	4725	do.....			do.....	Margin.....	do.....	do.....	Species undetermined. Quadriramaculatus.
July 6 Ang. 4 5 5 6	4727	Station 15.....				do.....	Open.....	Common.....	Species undetermined. Quadriramaculatus.
	4729	do.....				do.....	do.....	do.....	Do.....
	4748	Station 4.....	3	90	Willow stump.....	do.....	do.....	do.....	Species undetermined.
	4772	Station 2.....				Depression at margin.....	Shade.....		
Aug. 3 4 5 5 6	4774	Station 3.....		83		Hoofprints at margin.....	Open.....		Do.....
	4775	Station 4.....		84		do.....	do.....	Common.....	Do.....
	4776	Station 5.....	2	88	Willow.....	Margin.....	Shade.....		Do.....
	4783	Station 12.....		81-85		Hoofprints in channel.....	Open.....		Do.....
18 27 28	4784	Station 13.....		80-90		Mud cracks in channel.....	do.....		Quadriramaculatus.
	4783-10	Station 12.....		81		Hoofprints in channel.....	do.....	Common.....	Do.....
	7306	H85.....			Duckweed.....		do.....	do.....	Do.....
	7311	do.....			do.....		do.....	do.....	Do.....
Sept. 1 18	7315	Station 10.....				Shade.....	Shade.....		Punctipennis.
	7318	H85.....			Duckweed.....	Hoofprints in channel.....	Open.....		Do.....
Oct. 23 27 27 27 29	7355	Station 6.....				Depression at margin.....	do.....		Do.....
	7357	H79.....	2			Hoofprints in channel.....	do.....		Quadriramaculatus, punctipennis.
	7357	Dam station.....				Mud cracks in channel.....	do.....		Do.....
	7359	Station 3.....				do.....	do.....		
	7360	do.....							

¹ The collections after this date were made after the bayou was cleared but before the rains caused the water to back up over the cleared area by reason of the dam.

These records indicate general breeding of *Anopheles* throughout the course of the stream under natural conditions. *Anopheles quadrimaculatus* Say is the common species taken, and *Anopheles punctipennis* Say is second in numbers. It is noted that one collection of *Anopheles crucians* Wied. was made. The undetermined collections represent the *Anopheles* larvæ which were collected but which were not reared to the adult stage.

For convenience of the survey, the section of the bayou to be cleared of all vegetation was divided into stations 100 yards in length. The distance covered in the experiment was 1,600 yards, nearly a mile. The plants collected from this section, before clearing, during July and August, 1915, are shown in Table 2. The plants listed in Table 2 are distributed according to their location and the depth of water in the bayou in Table 3. The plant determinations were made by the Bureau of Plant Industry of this department. The natural conditions in the bayou, including the vegetation, water levels, and other features, are shown in Plate III, Figure 3; Plate IV; and Plate V, Figure 1.

TABLE 2.—Plants from Bayou Walnut, Mound, La., 1915.

Species.	Common name.	Location.
Spirogyra sp.....	Algæ.....	Submerged.
Lemna valdiviana, Lemna gibba, Spirodela polyrhiza, and Wolffia columbiana.....	Duckweed.....	Floating on water.
Jussiaea diffusa.....	Primrose-willow.....	In water, roots in bed.
Zizaniopsis miliacea.....	Aquatic grass.....	Do.
Cephalanthus occidentalis.....	Buttonbush.....	In channel and along margin.
Salix nigra.....	Swamp willow.....	Along margin, overhanging.
Bignonia radicans.....	Trumpet creeper.....	Do.
Brunnicliala cirrhosa.....	Buckwheat vine.....	Do.
Persicaria opelousana.....	Smartweed.....	Along margin.
Phytolacca americana.....	Pokeberry.....	Do.
Panicum colonum.....	Ditch grass.....	Do.
Asclepias perennis.....	Milkweed.....	Do.
Ampelopsis arborea.....	Peppervine.....	Do.
Belonging to family Euphorbiaceae.....	Spurge.....	Do.

TABLE 3.—Vegetation and depth of water in Bayou Walnut, Mound, La., before impounding, July–August, 1915.

Station.	Vegetation.			Depth of water in channel.
	Species.	Common name.	Location.	
Dam.	Lemna spp. ¹	Duckweed.....	Floating on water.....	6 inches to 11 inches.
	Jussiaea diffusa.....	Primrose-willow.....	In water.....	
	Cephalanthus occidentalis.....	Buttonbush.....	Bed and margin.....	
	Salix nigra.....	Swamp willow.....	Margin, overhanging.....	
	Persicaria opelousana.....	Smartweed.....	Margin.....	
	Zizaniopsis miliacea.....	Aquatic grass.....	Bed, in water.....	
	Euphorbiaceae.....	Spurge.....	Margin.....	

¹ The species of duckweed recorded under *Lemna* spp. in this list represent *Lemna valdiviana*, *L. gibba*, *Spirodela polyrhiza*, and *Wolffia columbiana*. Submerged algæ (*Spirogyra*) were common along the margins in some locations, but the submerged hornwort (*Ceratophyllum*) was not collected in this survey, though it is common in some other locations in the region.



FIG. 1.—View along edge of Bayou Walnut, natural conditions, showing open water in channel with grass-grown margin.



FIG. 2.—View along channel of Bayou Walnut, natural conditions, showing clean margin on opposite bank and vegetation along margin in immediate foreground.



FIG. 3.—Looking across Bayou Walnut, 200 yards above site of dam, before clearing.

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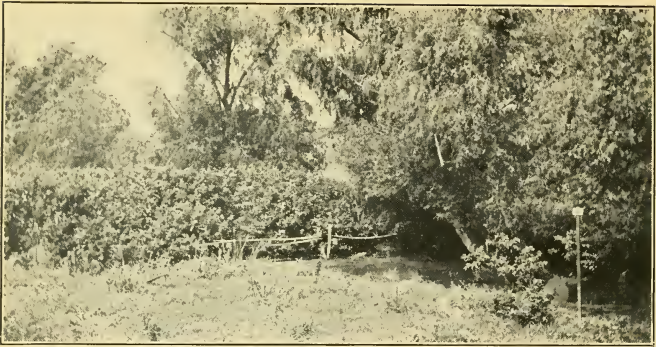


FIG. 1.—Looking down channel of Bayou Walnut, 300 yards above site of dam, before clearing.



FIG. 2.—Looking across Bayou Walnut, 500 yards above site of dam, before clearing.



FIG. 3.—Looking across Bayou Walnut, 900 yards above site of dam, before clearing.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

FISHES OF THE REGION.

A survey of the fishes of this region was made by the United States Bureau of Fisheries in cooperation with this work. This survey was intended to cover the distribution of the top minnow (*Gambusia affinis*) in this region; the possible presence of fishes other than this minnow that would be useful in mosquito destruction; the fishes valuable as food in the deeper and permanent areas of water; the survival of *Gambusia* in the impounded area in Bayou Walnut; and the possibility of establishing in the impounded area fishes that would be of value for food to the tenants on the plantation. This work was accomplished during 1916 and the early part of 1917. The fishes collected in Bayou Walnut under natural conditions are listed in Table 4. It is seen that *Gambusia affinis* is the prevalent species.

TABLE 4.—List of fishes taken in five collections in the natural area, Bayou Walnut, Mound, La., 1916-17.

Species.	Common name.	Number of collections.	Number of specimens.
<i>Gambusia affinis</i>	Top minnow.....	5	124
<i>Dorosoma cepedianum</i>	Hickory shad.....	1	20
<i>Lepomis cyanellus</i>	Green sunfish.....	1	20
<i>Lepomis humilis</i>	Sunfish.....	1	19
<i>Lepomis pallidus</i>	Blue-gill sunfish.....	1	4
<i>Lepomis symmetricus</i>	Sunfish.....	1	3
<i>Pomoxis</i> sp.....	.....	1	3
<i>Carpiodes</i> sp.....	.....	1	1

A point of special interest in connection with the natural conditions of the bayou is the fact that *Gambusia* is found in connection with general breeding of *Anopheles*. The breeding of these mosquitoes in the presence of comparatively large numbers of this minnow is accounted for by the protection afforded the mosquito larvæ by the aquatic and marginal vegetation and the vegetable debris upon the surface of the water. Further, the partially dry condition of the bayou at certain seasons provides isolated pools and water in hoof-prints of animals and in mud cracks from rains, to which the fish do not have access.

A complete list of the fishes collected in this region, not including the impounded area in Bayou Walnut and the Mississippi River, is shown in Table 5.

TABLE 5.—*List of fishes taken in 38 collections from seasonal and permanent waters (exclusive of Mississippi River) in the vicinity of Mound, La., 1916-1917, by F. M. Barnes, United States Bureau of Fisheries.*

Species.	Common name.	Number of collections.	Number of specimens.
<i>Gambusia affinis</i>	Top minnow.....	27	2,410
<i>Lepomis cyanellus</i>	Green sunfish.....	16	151
<i>Lepomis humilis</i>	Sunfish.....	10	126
<i>Lepomis megalotis</i>	Sunfish.....	4	6
<i>Lepomis pallidus</i>	Blue-gill sunfish.....	3	9
<i>Lepomis symmetricus</i>	Sunfish.....	2	4
<i>Lepomis ischyrus</i>	Sunfish.....	1	1
<i>Lepomis euryurus</i>	Sunfish.....	2	13
<i>Dorosoma cepedianum</i>	Hickory shad.....	12	483
<i>Notemigonus crysoleucas</i>	Roach, shiner.....	11	582
<i>Ameiurus nebulosus</i>	Common bullhead.....	11	198
<i>Ameiurus melas</i>	Black bullhead.....	1	1
<i>Pomoxis annularis</i>	Crappie.....	10	836
<i>Pomoxis sparoides</i>	Calico bass.....	9	104
<i>Chaenobryttus gulosus</i>	Warmouth bass, "goggle-eye".....	5	35
<i>Signalosa atchafalaya</i>	Shad.....	5	313
<i>Aphredoderus sayanus</i>	Pirate perch.....	4	20
<i>Roccus chrysops</i>	White bass.....	4	4
<i>Hybopsis hyostomus</i> (sp. ?).....	.....	4	20
<i>Micropterus salmoides</i>	Large-mouth black bass, "trout".....	3	5
<i>Micropterus dolomieu</i>.....	.....	2	4
<i>Hiodon alosoides</i>	Shad.....	3	21
<i>Hiodon tergisus</i>.....	.....	1	22
<i>Aplodinotus grunniens</i>	Fresh water drum, "gaspergon".....	3	6
<i>Centrarchus macropterus</i>	Round sunfish.....	2	60
<i>Ictiobus cyprinella</i>	Common buffalo.....	2	14
<i>Ictiobus bubalus</i>	Small-mouth buffalo.....	1	1
<i>Percina caprodes</i>	Log perch.....	2	2
<i>Amia calva</i>	Bowfin, "grinnel".....	2	4
<i>Lepisosteus tristoechus</i>	Alligator-gar.....	2	6
<i>Labidesthes sicculus</i>	Skipjack.....	2	5
<i>Stizostedion vitreum</i>.....	.....	2	5
<i>Elassoma zonatum</i>	Pigmy sunfish.....	1	75
<i>Fundulus chrysotus</i>	Killifish.....	1	8
<i>Ictalurus furcatus</i>	Blue cat.....	1	4
<i>Carpiodes thompsoni</i>.....	.....	2	2
<i>Carpiodes velifer</i>.....	.....	2	73
<i>Eupomotis</i> (sp. ?).....	.....	1	1
<i>Serranidae</i> (gen. ?, sp. ?).....	.....	1	1

A comparison between the numbers of *Gambusia* in the natural bayou and in all other classes of water shows an average of 25 specimens for each collection in the bayou and an average of 63 per collection for all other places. These figures indicate that these little fish are very abundant and very generally distributed in the region. The larger average per collection for all classes of water, as compared with the natural bayou, is explained by the fact that certain collections were made at the season of low stages of water which found these fish highly concentrated in some locations.

CLEARING THE BAYOU.

The clearing of the bayou was done during August, 1915. It was accomplished then for the reasons that the water in the stream was at its lowest level and that the plantation had finished its cultivation of the crops but had not as yet begun to harvest. This plan gave minimum water conditions and a supply of labor for the work without interference with the plantation operations. The smaller under-

growth was removed first, piled along the banks, and burned when sufficiently dry. The trees, logs, and stumps were then removed and placed upon the banks in suitable lengths for hauling away for use as firewood. In many instances the roots of the larger trees and old snags could not be removed without an amount of effort which would have added greatly to the cost of the work. These were sawed off even with the bed of the bayou and allowed to remain. They might have been removed rather cheaply by the use of dynamite, had the facilities for that work been available. The photographs represented by Plate III, Figure 3; Plate IV; and Plate V, Figure 1, give a very good idea of the extent and nature of the work that was done. The appearance of the stream during the operation of clearing is shown in Plate V, Figures 2 and 3.

CONSTRUCTION OF THE DAM.

In making the fill, or cross levee, for the dam, advantage was taken of a shallow point in the bed of the bayou used as a low-water crossing by the tenants. The banks at this point were favorable—that is, high enough on either side to allow the water to be raised to the required level. The required height of water was gained by running levels along the banks above the site of the dam. The dam was constructed to give a depth of 4 feet 10 inches at the floor of the spillway. When one recalls that the fall in the bed of the bayou in this section averages only 0.6 foot to the mile, it is seen that the level at the dam was carried back over the course of the stream for a considerable distance with only a slight variation in depth. The impounding was effective for depth about $\frac{1}{2}$ mile above the zone included in the survey, with the exception of a ridge which crosses the bed of the bayou just above the last station.

The details of the fill and spillway for the dam are shown in Figure 2 and in Plate VI, Figures 1 and 2. The completed dam, with bridge over the spillway, providing a roadway to the section of the plantation lying on the opposite side of the bayou, is shown in Plate VI, Figure 3. The labor and material involved in clearing the bayou and in the construction of the fill and spillway for the dam, are shown in Table 6. The bill of lumber for the spillway is shown in Figure 2.

TABLE 6.—*Cost of clearing a section of Bayou Walnut and impounding water in same, 1915.*

Preliminary survey, running levels, plan and specifications of spillway—	\$45.00
Clearing undergrowth and grass from bed and edges of bayou, including piling and burning:	
15 men, 6 days, at \$1.25—	\$112.50
3 men, 5 days, at \$1—	15.00
	127.50



FIG. 1.—Looking up channel of Bayou Walnut, 1,500 yards above site of dam, before clearing.

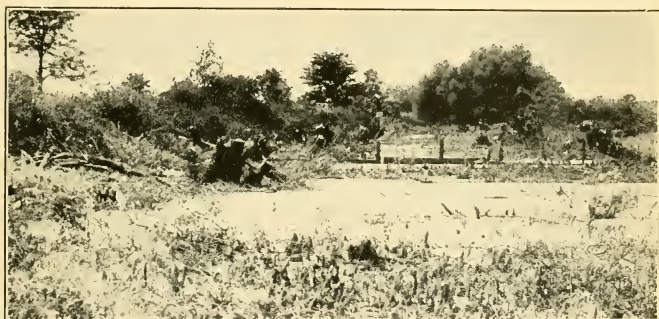


FIG. 2.—Looking up channel of Bayou Walnut during the work of clearing, from point 300 yards above site of dam.



FIG. 3.—Looking up channel of Bayou Walnut from site of dam, after channel has been cleared and undergrowth piled along banks.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

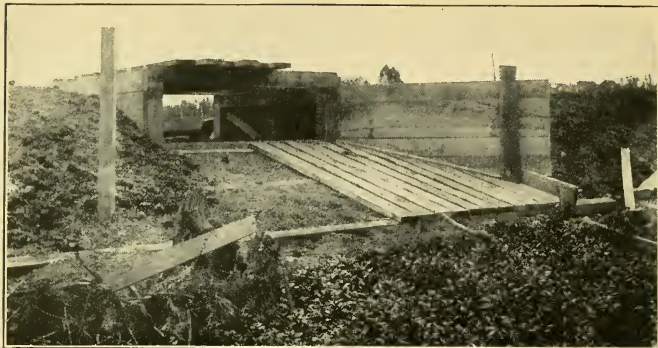


FIG. 1.—View showing construction of spillway-box and downstream apron in dam.

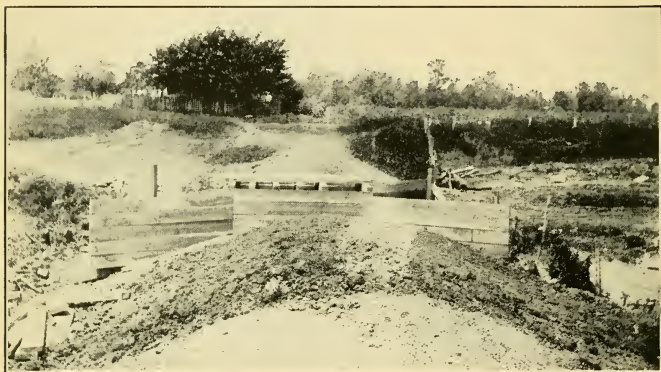


FIG. 2.—View across Bayou Walnut showing wing walls of spillway and bridge over spillway box.

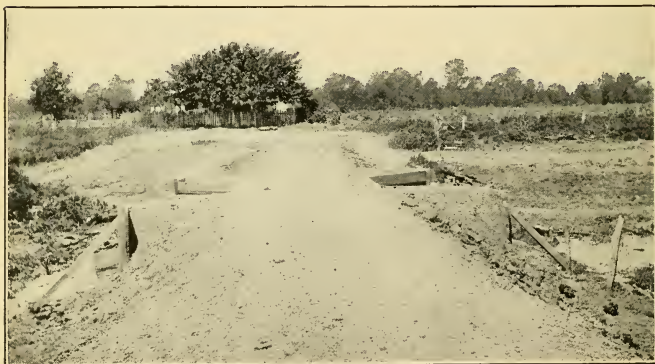


FIG. 3.—View across Bayou Walnut at site of dam, showing roadway to opposite side of bayou.
IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

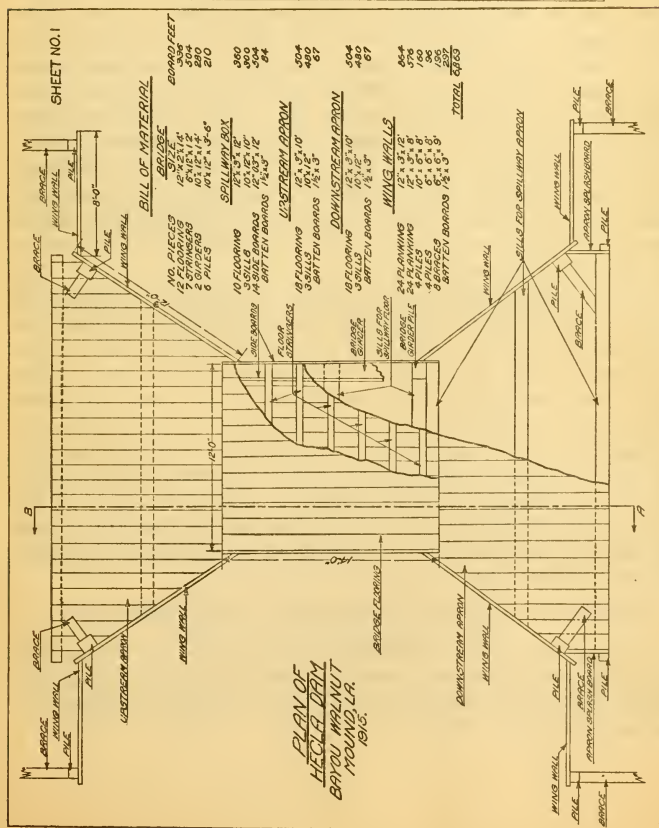


FIG. 2.—Plan of Hecla Dam, Bayou Walnut, Mound, La., 1915.

Removal of trees and stumps and cutting into suitable lengths for hauling away:

16 men, 8 days, at \$1.25-----	\$160. 00	
1 team and driver, 4 days, at \$3-----	12. 00	
		\$172. 00
Raking edges and burning trash, 4 men, 6 days, at \$1-----		24. 00
Fill or cross levee at dam, 6 teams and drivers, 5 days, at \$3-----		90. 00
Lumber for spillway, 7,000 square feet cypress, at \$18 per M-----		126. 00
Carpenter work on spillway:		
1 carpenter, 6 days, at \$2.25-----	13. 50	
1 helper, 6 days, at \$1.50-----	9. 00	
2 helpers, 2 days, at \$1-----	4. 00	
		26. 50
Total-----		\$611. 00

MAINTENANCE WORK FOLLOWING CLEARING AND CONSTRUCTION.

A comparison of the cleared bayou, before the water backed up over the bed, with the natural conditions that have already been shown, may be made from the illustrations in Plate VII and Plate VIII, Figure 1. These views were taken after the undergrowth had been burned and the wood from the trees and logs had been hauled away. Later in the year, at the onset of the winter rains, the water began backing over the bed above the dam. This condition is shown in Plate VIII, Figure 2. It is noted that quite an amount of débris was floated to the surface. As the water level was raised, this floating material collected along the margins, and this was cleaned out with rakes and burned. The appearance of the bayou later in the season, when filled with water, is shown in Plate VIII, Figure 3, and Plate IX, Figure 1.

The only maintenance work, in so far as vegetation is concerned, was the clearing of the "floatage" along the banks following the first rise of water and cutting back a comparatively small amount of second growth, mostly grass (*Zizaniopsis miliacea*) and willow shoots that found their way to the surface of the water the following spring. These shoots were removed by the use of a boat and a curved knife on a long handle. Maintenance work has been required on the dam by reason of the work of crawfish, *Cambarus* sp., about the spillway, and this difficulty, as well as the effect of the work of the crawfish on the water level above the dam, and in turn the effect of the change in water level on the marginal vegetation, will be discussed later.

SURVEY OF ANOPHELES BREEDING AFTER IMPOUNDING.

A comparison of the Anopheles breeding in the impounded area and in the natural bayou is shown by the collections in the general survey work for the years 1916 and 1917. The records for these collections are listed in Table 7.

TABLE 7.—*Collections of Anopheles larvae, Bayou Walnut, Mound, La., 1916-17.*

Date.	Record No.	Locality.	Water.		Vegetation.	Character of location.	Amount of Shade.	Gambusia present.	Species.
			Depth.	Temp.					
1916. July 26 Aug. 2	194	H84	Inches.	° F.	Jussiaea	Channel	Shade	Very abundant	Quadrinaculatus.
	201	H151			Spirogyra	Margin	Open	Common	Do.
	201	H151			Bushes and floatage.	Channel	Shade	do.	Do.
	205	H151		86	Spirogyra	Margin	Open	do.	Do.
	205	H153	36	86	Grass and floatage.	Channel	Part shade	do.	Do.
1917. June 11 11 11 26 26 July 14	1683	300 yards below dam		76	Willow	do.	Shade	do.	Do.
	1684	do.	3-10	77	Shrubs	Margin	do.	do.	Do.
	1685	U. S. B. F. Station 2	8	88	do.	do.	Part shade	do.	Do.
	1699	U. S. B. F. Station 1	12	77	do.	do.	Open	do.	Species undetermined.
	1700	do.	6	77	Duckweed	do.	Part shade	do.	Quadrinaculatus.
	1904	U. S. B. F. Station 5		94	Grass	do.	Open	do.	Do.
	B17	H153	6-12	79	Willow and floatage.	do.	Part shade	do.	Do.
	B18	U. S. B. F. Station 2		91	Duckweed	do.	Shade	Abundant	Species undetermined.
	B23	H153		90	Floatage	Channel	Open	Common	Quadrinaculatus.
	B33	U. S. B. F. Station 1	15-18	96	Duckweed	Margin	Open	do.	Do.
	B34	H153	15-18	88	Willow	do.	Shade	do.	Species undetermined.
	B37	U. S. B. F. Station 1	6-8	86	Buttonbush and willow.	do.	do.	do.	Quadrinaculatus.
	B40	H153	15	81	Willow	Channel	do.	do.	Do.
	B44	H153	9	84	do.	do.	do.	Abundant	Species undetermined.
	B47	U. S. B. F. Station 1	6-8	79	Duckweed	do.	do.	do.	Do.

It is seen that the collections are confined to the sections of the bayou below the dam and to the backwater above the impounded zone. No specimens were taken in the collections in the impounded area proper. The section of the bayou above the impounded area was clear for a distance of about $\frac{1}{2}$ mile and the backwater gave favorable conditions for nonbreeding in this distance with the exception of a limited area just above the last station where a ridge crosses the bed of the bayou and where the aquatic grass (*Zizaniopsis miliacea*) persisted, as shown in Plate IX, Figure 2. The maximum depth where this grass survived was about 1 foot. Below this point to the dam, a distance of nearly a mile, an average depth of $3\frac{1}{2}$ feet was maintained which was sufficient to suppress this grass as well as all other vegetation in the channel. Another location of *Anopheles* breeding found above the impounded zone was some distance above the growth of grass mentioned, among willows and other vegetation characteristic of natural bayou conditions. This location is shown in Plate IX, Figure 3.

FISHES IN THE IMPOUNDED AREA.

A survey of the fishes in the impounded area in Bayou Walnut, the results of which are given in Table 8, shows that the top minnow (*Gambusia affinis*) finds no difficulty in establishing itself under the conditions of deeper and open water. The fish collections in this water also show that the larger fishes of the region, those of value for food, have found their way to the impounded area in some numbers. The more valuable of these for food are the crappie or "white-perch" (*Pomoxis annularis*), the calico bass (*Pomoxis sparoides*), the large-mouth black-bass or "trout" (*Micropterus salmoides*), and the warmouth bass or "goggle-eye" (*Chaenobryttus gulosus*). These game fishes are largely predacious and of course take their toll from the *Gambusia*, but this feeding of these larger fishes upon the little top minnows must not be viewed so much in the light of the reduction of the mosquito-eating minnows as from the standpoint that the patrol work which they do serves to keep the little fishes in the shallow water along the margins. In the open water of the impounded area there is no mosquito breeding and since the salvation of the little fishes depends upon their remaining along the margin to escape the larger fishes, the value of the larger fishes as an indirect aid in mosquito control is seen.

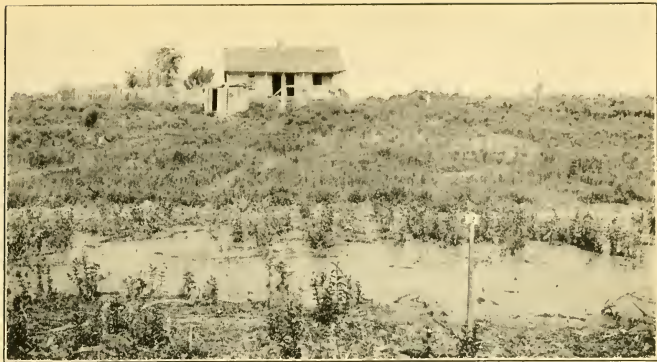


FIG. 1.—View across Bayou Walnut, after clearing, 200 yards above site of dam. Compare with Plate III, Figure 3.

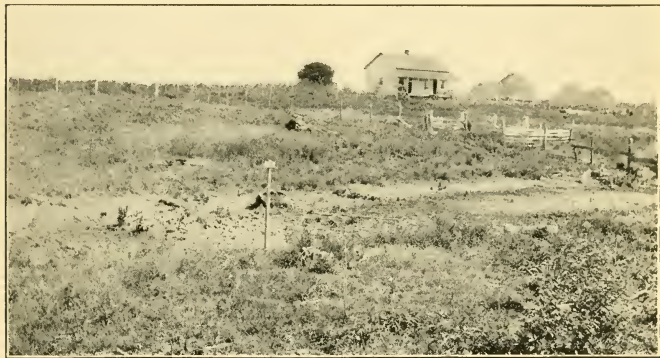


FIG. 2.—View across Bayou Walnut, after clearing, 300 yards above site of dam. Compare with Plate IV, Figure 1.

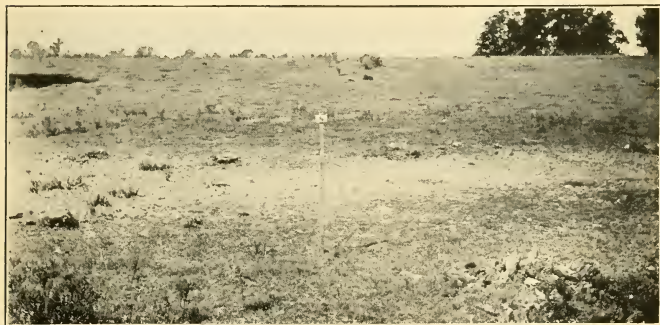


FIG. 3.—View across Bayou Walnut, after clearing, 800 yards above site of dam.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

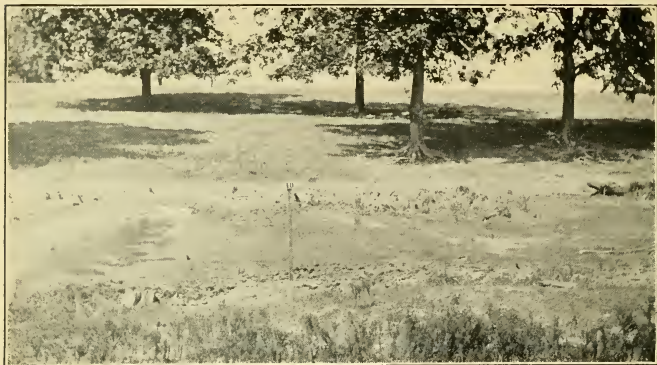


FIG. 1.—View across Bayou Walnut, after clearing, 1,000 yards above site of dam.

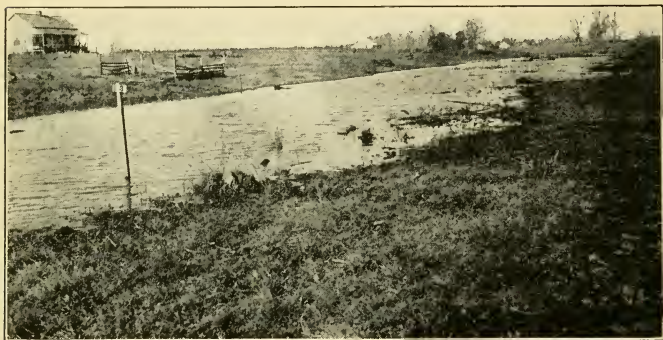


FIG. 2.—Looking up channel of Bayou Walnut, after first rise of water, from point 300 yards above site of dam. Note "floatage" along margin. Compare with Plate IV, Figure 1, and Plate V, Figure 2.



FIG. 3.—View above dam, Bayou Walnut, with bayou filled with water. Compare with Plate V, Figure 3.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.



FIG. 1.—View toward dam and spillway, Bayou Walnut, from upstream, showing bayou filled with water.



FIG. 2.—View across Bayou Walnut, showing aquatic grass, *Zizaniopsis miliacea*, in bed of bayou, above impounded zone.



FIG. 3.—View along margin of Bayou Walnut, above impounded zone, showing natural bayou conditions.

IMPOUNDING WATER TO CONTROL MALARIA MOSQUITOES.

TABLE 8.—*List of fishes taken in 12 collections in the impounded area, Bayou Walnut, Mound, La., 1916-17, by F. M. Barnes, U. S. Bureau of Fisheries.*

Species.	Common name.	Number of collections.	Number of specimens.
<i>Gambusia affinis</i>	Top minnow.....	7	163
<i>Lepomis cyanellus</i>	Green sunfish.....	7	95
<i>Lepomis humilis</i>	Sunfish.....	6	89
<i>Lepomis pallidus</i>	Blue-gill sunfish.....	1	1
<i>Lepomis ischyrius</i>	Sunfish.....	1	1
<i>Lepomis symmetricus</i>	do.....	1	1
<i>Lepomis megalotis</i>	do.....	1	1
<i>Pomoxis annularis</i>	Crappie.....	5	103
<i>Pomoxis sparoides</i>	Calico bass.....	3	25
<i>Ameiurus nebulosus</i>	Common bullhead.....	5	43
<i>Dorosoma cepedianum</i>	Hickory shad.....	5	15
<i>Notemigonus crysoleucas</i>	Roach, shiner.....	3	151
<i>Aphredoderus sayanus</i>	Pirate perch.....	2	3
<i>Micropterus salmoides</i>	Large-mouth black bass.....	2	2
<i>Micropterus dolomieu</i>.....	.....	1	3
<i>Chaenobryttus gulosus</i>	Warmouth bass, "goggle-eye".....	1	12

In the comparison of the numbers of the top minnows found per collection in the natural bayou and in all other classes of surface water it was seen that for all classes of water there was an average of 63 *Gambusia* per collection and for the natural bayou 25 specimens per collection. From the figures in Table 8 we find an average of 14 specimens of *Gambusia* for the 12 collections made in the impounded water. Just as the comparison of the numbers of these fish in the natural bayou and in all other classes of water is influenced by the fact that some of the collections in the latter case were made in locations where the fishes were highly concentrated, so in the impounded water, as compared with the natural bayou, we must consider the effect of great dilution in the former. It is sufficient for the practical results of the work to note that the *Gambusia* survived in important numbers the effects of the impounding, and that the presence of the game fishes in the area serves the purpose of keeping the top minnows along the margins where they are useful in the marginal control of mosquito breeding.

FACTORS PREVENTING MOSQUITO BREEDING IN THE IMPOUNDED WATER.

The nonbreeding of *Anopheles* in the impounded water is due to a number of factors which have not as yet been definitely measured. In general, as has been stated, the important difference between the impounded section of the bayou and the natural bayou is just the difference between lakelike conditions which do not favor the development of *Anopheles* and swamplike conditions which do favor such development. The factors which are considered to operate against mosquito development are the greater freedom for action on the part of the predators, the fish and the aquatic insects; wave action; depth, which influences temperature of the water; absence

of the vegetable shelter, which operates against the concentration of adults along the bayou and consequent oviposition; and depletion of the larval food of *Anopheles* furnished by the decaying vegetation and the low forms of aquatic life, both plant and animal, common to the swamplike conditions of the natural bayou.

LEAKAGES CAUSED BY CRAWFISH AND MEANS OF PREVENTING THEM.

The work of maintenance at the dam due to the action of crawfish about the boxing of the spillway has been mentioned. The crawfish burrowed through the fill below the level of the water above the dam to the lower side of the fill. The action of the water through these openings in carrying away the dirt caused serious leakage, which resulted in a decidedly lower level of water above the dam. In several instances the level of the bayou was lowered materially before proper repairs in the dam were made. This damage was not serious the first year following the completion of the dam, but during the following years, up to 1920, considerable expense was involved in preventing the leakage in the dam due to the work of the crawfish. In 1920, a double course of sheet piling with overlapping joints was driven below the fill, leaving an opening for the spillway, the boxing of which was carried through and over the sheet piling. This served to prevent the crawfish from working to the outside, below the fill, and to hold the water above the dam at a permanent level.

An important biological observation was made in connection with the variable water level caused by the leakage in the dam due to the crawfish. It was found that when the water was lowered, after remaining at one level for a period, the water found a clean edge free from debris and grass and, further, that the drying out above the new level served to destroy the aquatic and semiaquatic vegetation that had gained a foothold. Then when the leakage had been repaired and the water level raised to its original height, it rested against comparatively clean margins. The growth of marginal vegetation was thus discouraged by this variable water level, and this explains the lack of any maintenance work on control of marginal vegetation in the impounded area. Thus, the expense in the maintenance work on the dam was offset in part by the saving in the work on the margins.

The experience with the crawfish suggests two improvements to be considered in any further work on impounding water in a bayou in this region. The first is the prevention of injury to the fill in the dam on the part of crawfish. This can be accomplished by a core wall extending below and to each side of the spillway box in the center of the fill. The second is provision for controlling the water level above the dam. The object of this is to make use of the effect

of a variable water level on marginal vegetation and marginal breeding. This is obtained by a change in the water level from time to time. This can be accomplished by a sluiceway through the fill below the level of the floor of the spillway. The flow of water through the sluiceway can be controlled by a gate. If the sluiceway is placed at the level of the bed of the bayou, in the center of the fill, it will act efficiently in lowering or raising the water level above the dam, and, also, the current of water through the sluiceway at this point will flush out and carry away the mud and sediment that tend to accumulate in the bed immediately back of the fill.

ADVANTAGES OF IMPOUNDING, APART FROM PREVENTION OF ANOPHELES BREEDING.

A special advantage to the plantation, apart from the control of Anopheles breeding in the bayou, is the fact that the impounded water gives an ample supply of good water for the live stock throughout the dry summer season. The land lying between the roadway and the bed of the bayou is ordinarily used for pasture purposes by the tenants living along the stream. Except in some instances where clearing has been done in a comparatively wide strip of land found between the road and the channel of the bayou, the pasture along the stream is limited in extent and the grasses are crowded out by weeds, bushes, trees, and vines. During the seasons of dry weather the water in the natural bayou is shallow and stagnant. The supply is often difficult of access by reason of the tangle of overhanging and aquatic vegetation. The animals often become bogged in seeking the water, and the more shallow and isolated pools are converted into wallows, particularly where hogs are pastured along the bayou side. The situation under these conditions is unsightly and insanitary and the supply of water is limited in amount and of the poorest quality. With the limited pasturage the animals do not thrive, and often die. The pasture for the plantation stock—that not owned by the tenants—is the wet land lying between the cultivated areas and the timber and swamp. These pasture lands extend into the timber and the live stock depend upon the swamps and the shallow lakes in the basins of same for water. In any prolonged dry season this supply becomes greatly restricted and as objectionable in quality as that in the bayou. When this situation becomes acute it is necessary for the plantation to drive wells throughout the pasture areas and pump water. This adds greatly to the expense of taking care of the stock. On Hecla plantation, following the clearing of the section in Bayou Walnut and impounding the water, the management not only extended the fencing to include the entire impounded area, but also arranged the fencing of the pastures in one section of the plantation so that by a system of gates the live stock

from the regular pastures could visit the impounded water. The impounding was effective for depth, in so far as an abundant and good water supply is concerned, for a distance of nearly 2 miles and thus furnished water for all of the stock of the tenants living along the stream and for the larger portion of the plantation live stock during the dry seasons as well. The clearing served to increase the amount of available pasture, particularly of value to the tenants for their cows and work animals, and the feeding of these animals along the impounded water aided in the suppression of the marginal vegetation. The management of the plantation has stated that the advantage of a permanent supply of good water for the live stock would alone justify the expense of the clearing and the impounding project.

The owners of Hecla plantation are also operating a lumber mill at Mound. Before impounding the water in Bayou Walnut, the source of water for the boilers at the mill was a driven well. This water proved undesirable for boiler purposes by reason of the salts which were precipitated in the generation of steam. This caused some expense and considerable loss in time at the mill. A pipe line was laid from the bayou to the mill and the impounded water pumped to same for boiler purposes. The management of the mill has stated that the saving in the mill expenses would more than justify an annual expense equal to the cost of the project. In fact, the mill management contributed very largely the funds for maintenance at the dam made necessary by the injury from the crawfish.

A further advantage is gained in that the impounded water offers a source of fish for food. The bass, or "trout," and the crappie, or "white perch," are now present in some numbers. The "buffalo" (*Ictiobus cyprinella*) has been caught occasionally and will no doubt increase in numbers, and the sunfish (*Lepomis* spp.), or "bream," are common. The tenants are able to do a considerable amount of line fishing and every catch adds to the supply for their tables, furnishing a valuable food and a saving in meat.

An advantage not to be overlooked is the great improvement in the property which adds to its value. The further value of the impounded area of the bayou as a place of recreation for the tenants is a very practical point in plantation economy which should be given consideration.

SUMMARY.

The bayous, or streams, of the Delta region flow away from the river, their banks are higher than the surrounding lands, and the fall in their beds is very slight. The shallowness of water in these streams, with prevalent aquatic and overhanging vegetation, favors the development of *Anopheles* mosquitoes. The peculiar relation

of these streams to the surrounding topography does not permit drainage. In the absence of a drainage outlet, the Bureau of Entomology conceived the idea of clearing a section of one of the bayous and impounding the water to note the effect of a change from the swamplike conditions of the natural bayou to the lakelike conditions of the impounded area, on the capacity of the bayou for *Anopheles* production.

It is important to control breeding of *Anopheles* in bayous for the reason that these streams offer a near-by source of mosquitoes, since the houses on a plantation in the Delta are located on the roadways along the bayou banks, where one of these streams sections or bounds a property.

A section of Bayou Walnut at Mound, La., was cleared of all vegetation and the water in this area impounded by means of a cross-levee, or fill, and spillway. This served to keep the water over the bed of the stream above the dam at a sufficient height to suppress the further growth of vegetation.

It was found by comparative studies that this clearing and impounding was effective in preventing the breeding of *Anopheles* in the bayou where formerly such breeding was common.

Cooperative work on the part of the United States Bureau of Fisheries demonstrated that the mosquito-eating top minnow (*Gambusia affinis*) is generally distributed in the region, but that under natural delta conditions this minnow is found coincident with prevalent breeding of *Anopheles*. It was also demonstrated that this minnow has established itself in important numbers along the margins of the impounded area. One of the important factors in the natural control found to exist in the impounded water is believed to be the greater freedom for action which the condition of an open surface of water gives to these fish and to aquatic predacious insects. The fish are noneffective in control under natural conditions by reason of the protection afforded the mosquito larvæ by the aquatic and marginal vegetation and the vegetable débris upon the surface of the water. Other factors in the natural control in the impounded zone are considered to be wave action, influence of a greater depth on breeding, absence of shelter for adults along the course and consequent reduction of oviposition, and the depletion of the food of *Anopheles* larvæ.

The important points to be considered in impounding water in a bayou for mosquito control are the preliminary clearing of all vegetation, the provision for a permanent level of water sufficiently high to suppress the further growth of aquatic and semiaquatic vegetation, and the maintenance of a clean margin.

A further point in the construction of the dam is provision to prevent the work of crawfish, which, otherwise, work through the fill and cause serious leakage. The water level in the project under dis-

cussion varied greatly at times, due to failure to make such provision. However, from this variable level which occurred, the experience was gained that such fluctuation in level operated as an aid in the control of the marginal vegetation which otherwise would have gained a foothold and would have required an expenditure for the maintenance of clean margins. The suggestions are made that the crawfish injury can be prevented by a core wall through the center of the fill to either side and below the box of the spillway in the dam, and that a variable water level can be secured by a sluiceway, with control gate, through the fill and core wall.

Advantages to the plantation from the impounding work, apart from the control of *Anopheles* breeding, are a permanent supply of good water for live stock during the dry season; an extension of the land available for pasture; the deeper and more extensive water of the impounded area, which offers a favorable place for game fish and thus furnishes a source of food; and the lake-like body of water which offers recreation to the plantation people and adds to the attractiveness and value of the property.

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